Agilent ParBERT 81250 Measurement Software

Output Level Measurement User Guide

Agilent Technologies

Important Notice

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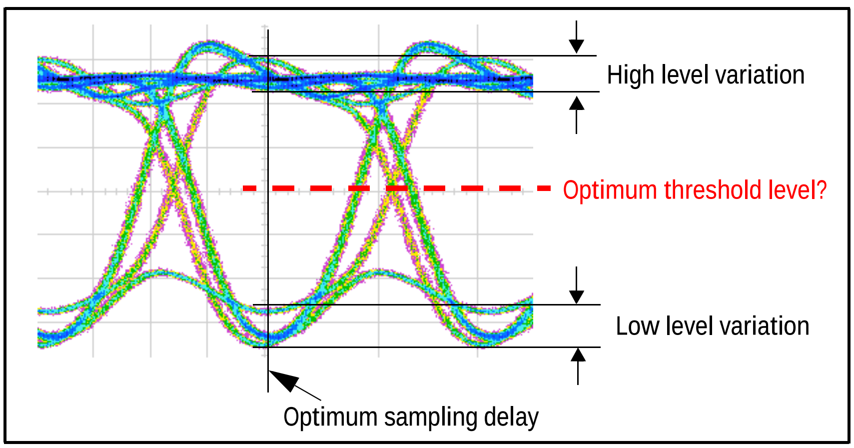
Introduction

The Output Level measurement allows you to set up and run a bit error rate (BER) measurement for a device under test (DUT) with several output ports and terminals.

The sampling delay is fixed. The analyzer decision threshold is automatically swept within a user-defined range. At each step, the BER is measured.

The measurement can be used for investigating the behavior of the DUT. A direct result is the determination of the optimum analyzer threshold level for receiving data from the DUT with maximum confidence.



The Output Level measurement provides three graphical views:

- BER vs. Threshold

  This graph shows the relationship between the analyzer decision threshold and the resulting BER. It presents the raw data.

- dBER vs. Threshold

  This graph shows the relationship between the analyzer decision threshold and the derivative of the bit error rate (dBER/dTh). A Gaussian marker allows you investigate the peaks of this graph.

- QBER vs. Threshold

  This graph shows the extrapolation of the Q-factor and the optimum threshold level from a limited number of measured points.

Variable Decision Threshold Method

The method used by this measurement is commonly known as *Variable Decision Threshold Method*. It provides a “vertical” analysis of the eye opening seen by the receiver(s). This method allows you to determine more than just the actual levels.

The Output Level measurement calculates also the Q-factor (a measure that describes the quality of the received signal) and derived values. These results can assist you in characterizing the device. They can also enable you to predict very low bit error rates that would take a long time to be measured.

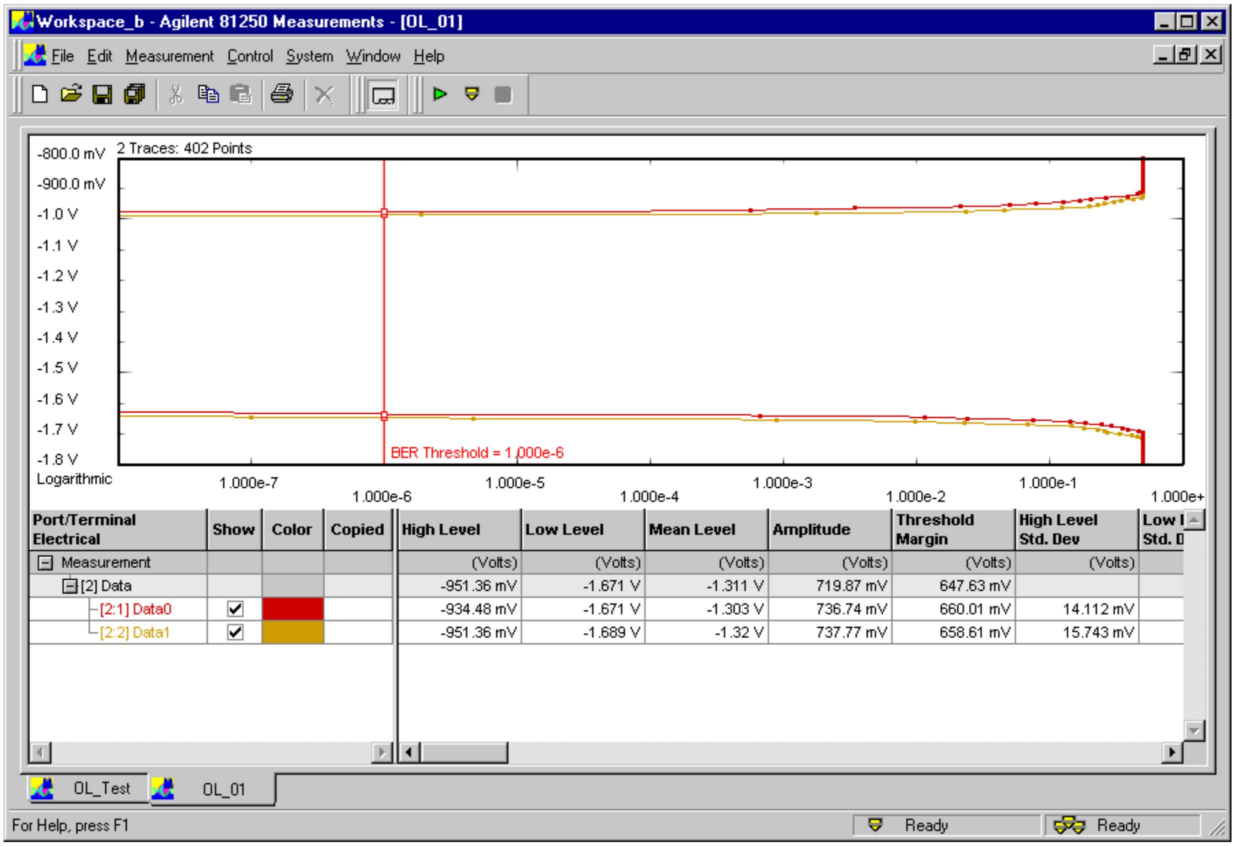
About this manual

This document provides the following information:

- For a quick start, read the example session given in *“Example of an Output Level Measurement” on page 9*.
- *“Basics of the Output Level Measurement” on page 27* provides detailed information on the prerequisites and the parameters shown on the result screens.
- *“Setting the Properties of an Output Level Measurement” on page 47* shows how to specify the input parameters and the graphical display of the measurement.

NOTE It is assumed that you are familiar with the general characteristics and features of the *Agilent 81250 Measurement Software*. The general capabilities and operating principles are documented in the *Agilent 81250 ParBERT Measurements Framework User Guide*.

The following illustration shows the result of a simple Output Level measurement performed on two channels:



Example of an Output Level Measurement

This chapter shows you how to set up and perform an Output Level measurement:

1. Use the *Agilent 81250 User Software* for connecting the device under test with the system.

   See *"Setting Up and Connecting the DUT" on page 10*.

2. Prepare a bit error measurement with the *Agilent 81250 User Software*.

   See *"Preparing the Measurement" on page 11*.

3. Use the *Agilent 81250 Measurement Software* for creating a workspace and measurement and run the measurement.

   See *"Executing an Output Level Measurement" on page 14*.

4. Adapt the display to your needs.

   See *"Improving the Output Level Display" on page 19*.

5. Change the measurement properties and see the results.

   See *"Changing the Output Level Properties" on page 21*.

6. Compare the results of two or more measurements.

   See *"Comparing Output Level Measurement Results" on page 24*.

Hardware requirements

For this example, we use the following ParBERT hardware components:

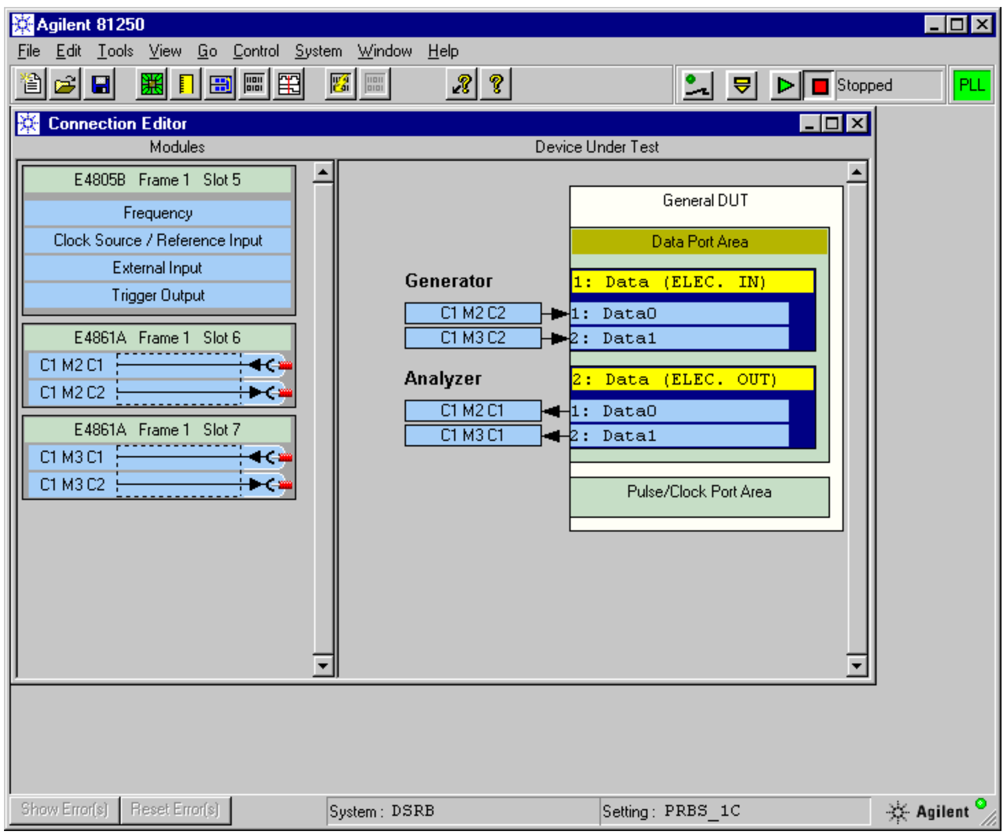
- Two E4861A 2.7 GHz data generator/analyzer modules
- Two E4862A generator frontends
- Two E4863A analyzer frontends

Setting Up and Connecting the DUT

Use the *Agilent 81250 User Software* to create a model of the hardware. For a detailed description of the *Agilent 81250 User Software*, refer to the *Agilent 81250 ParBERT System User Guide*.

1 Create a DUT input port and a DUT output port.

2 Connect the generators to the DUT input port and the analyzers to the DUT output port.

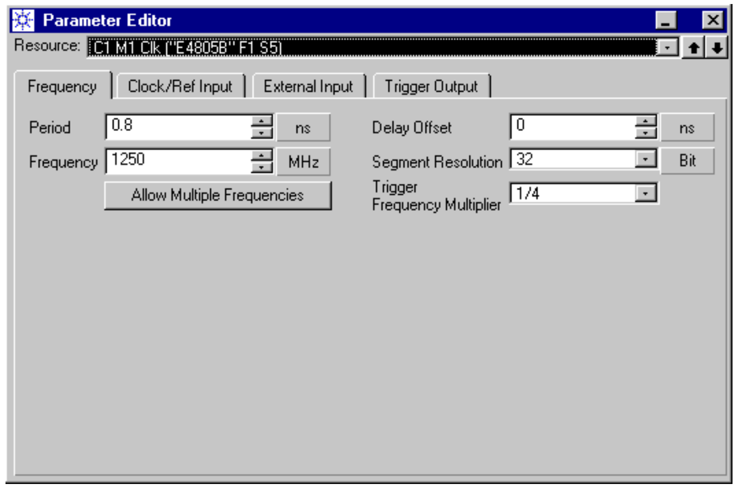


3 Using two shielded SMA cables, connect the analyzers physically with the generators. The cable connections will be our device under test.

Preparing the Measurement

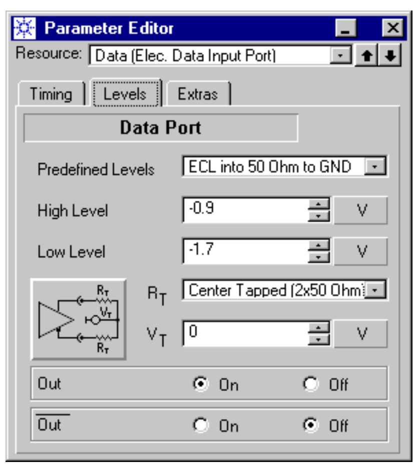
Use the *Agilent 81250 User Software* to prepare a bit error rate test:

1 Adjust the clock frequency, if desired.



We use a clock rate of 1250 MHz in this example. This corresponds to a clock period of 0.8 ns.

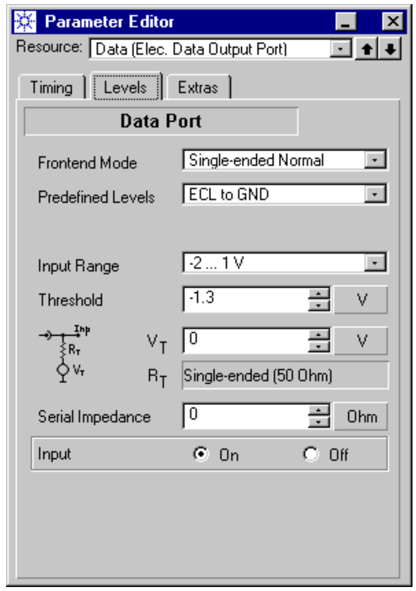
2 In the Connection Editor, double-click the DUT input port. Set the high and low voltage levels of the generator frontends and switch the frontends on.



We use a predefined level in this example.

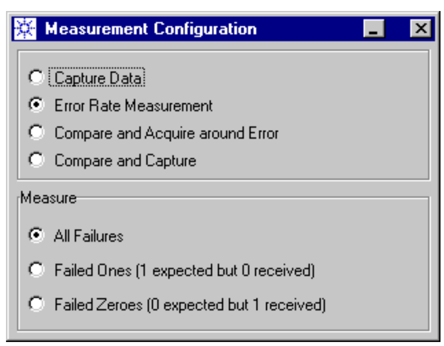
3 In the Connection Editor, double-click the DUT output port. Set the *Frontend Mode* of the analyzers to *Single-ended Normal*. Set the

Level and *Threshold* so that they fit to the generators. Switch the analyzers on.



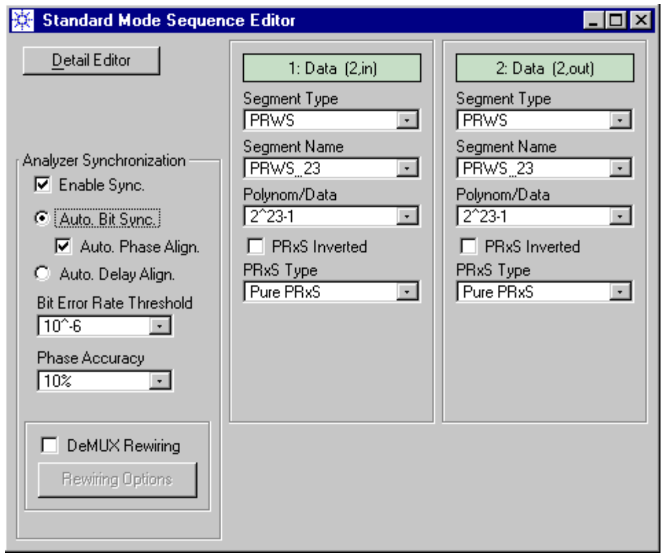
Measuring eye openings requires an analyzer threshold voltage. If you set the *Frontend Mode* to *Differential,* you have to select one of the *Analyzed Inputs*. The Output Level measurement cannot be performed in fully differential mode.

4 Ensure that the measurement mode ist set to BER. This is the default.



5 Create the test sequence with the *Standard Mode Sequence Editor*. We use the same PRWS segment for both ports.

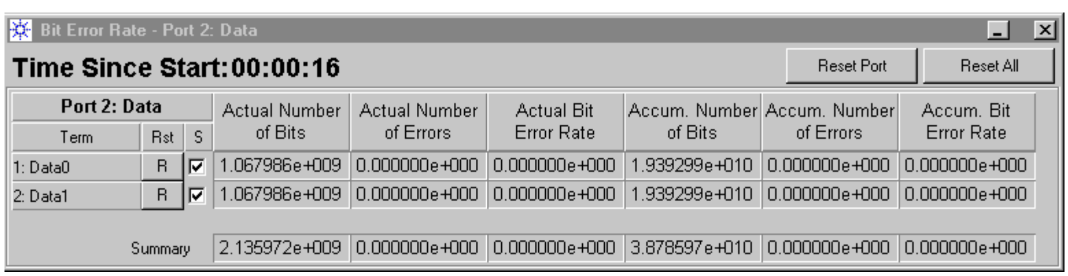
6 Enable *Automatic Bit Synchronization* with *Automatic Phase Alignment*.



Automatic Bit Synchronization with *Automatic Phase Alignment* ensures that the analyzers will position their sampling point automatically at the optimum, no matter what the total signal delay is.

You could also use *Automatic Delay Alignment*, but this generally requires that you specify a suitable analyzer start delay with the Parameter Editor.

7 Make a quick test to ensure that everything has been set up correctly. Open the Bit Error Rate display and then click the Run button.



The BER should be zero.

8 From the *File* menu, use *Save Setting As* to save the setting. We use the name *PRBS_1C* in this example.

Once you have saved the setting, you may terminate the *Agilent 81250 User Software,* if you wish to do so.

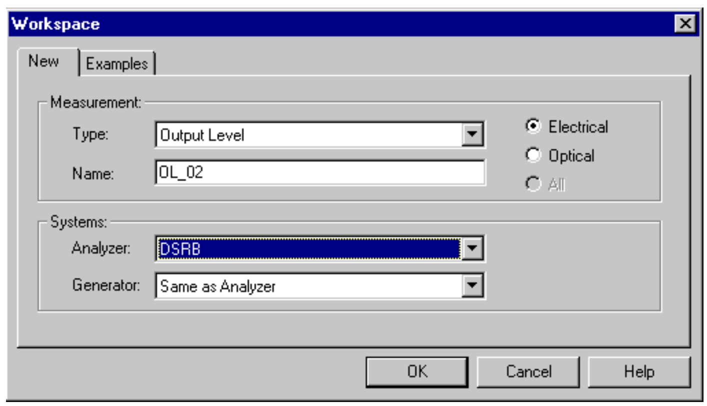
Executing an Output Level Measurement

Use the *Agilent 81250 Measurement Software* to set up and perform the Output Level measurement:

1 Start the *Agilent 81250 Measurement Software.*

The *New* page of the *Workspace* dialog appears.

2 Select the measurement type *Output Level*. If desired, assign a name to the measurement. Otherwise it is automatically named. Select the *Analyzer System* from the drop-down list.

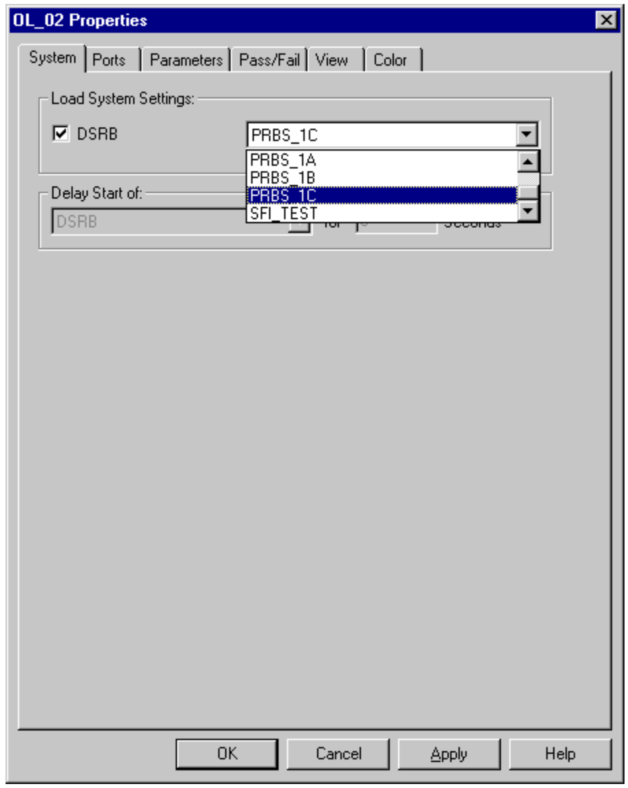


We use electrical analyzers in this example and only one system (DSRB). In case of two systems you would also select the generator system.

3 Click *OK*. This creates a new measurement and opens the measurement*'s Properties* dialog.

The *System* page shows the chosen system(s).

4 If no setting is loaded on the system(s) or not the setting you need, click the checkbox by the side of the system's name. Then choose a suitable setting from the drop-down list.

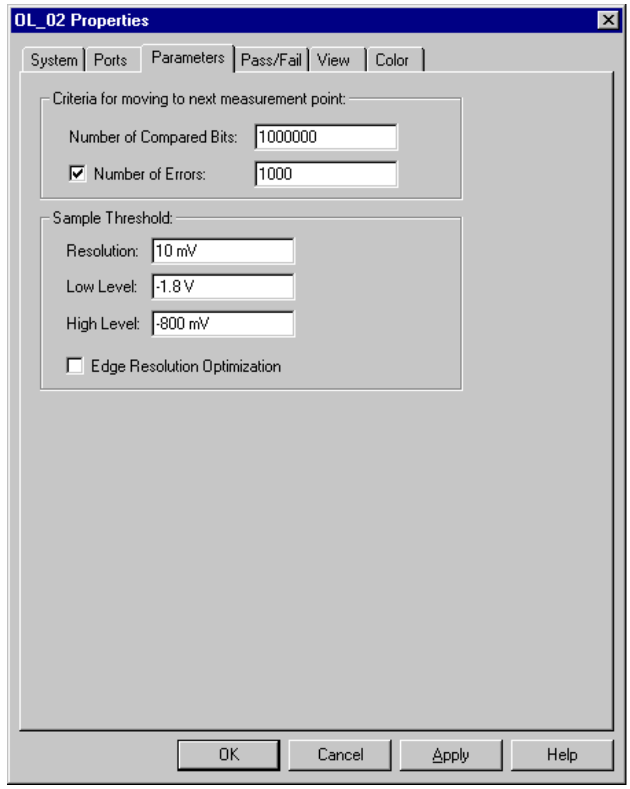


We have chosen the previously created setting PRBS_C.

5 Click *Apply*. This downloads the setting without terminating the *Properties* dialog.

6 Click the *Parameters* tab.

7 Set the *Sample Threshold* parameters to suitable values that fit to the expected signal levels. Set the *Resolution* to 10 mV.

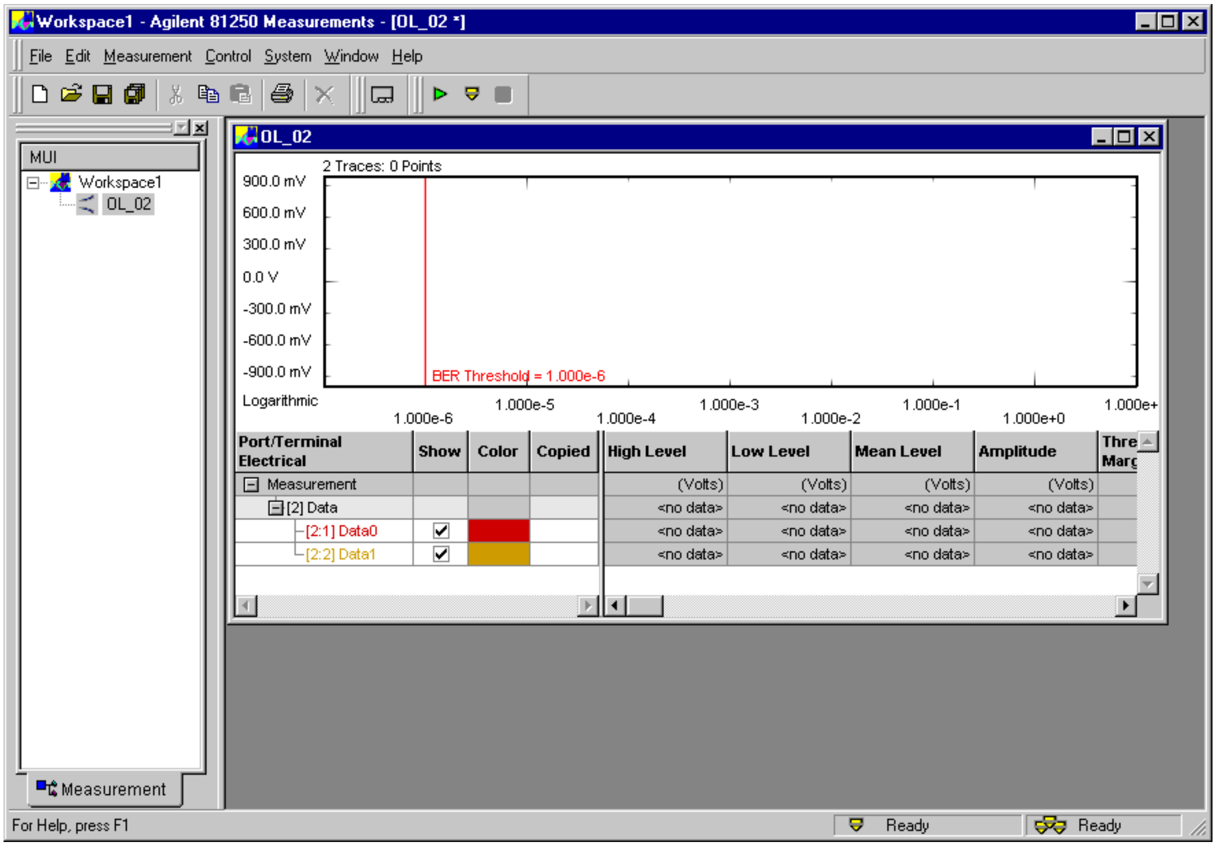


In this example, we expect the signal voltages we have specified for the generators: –1.7 V to –0.9 V. The *Sample Threshold* values shown in the figure above cover this range well.

The *Resolution* is the size of the steps when the threshold moves from the low to the high level. A resolution of 10 mV means 100 steps per Volt.

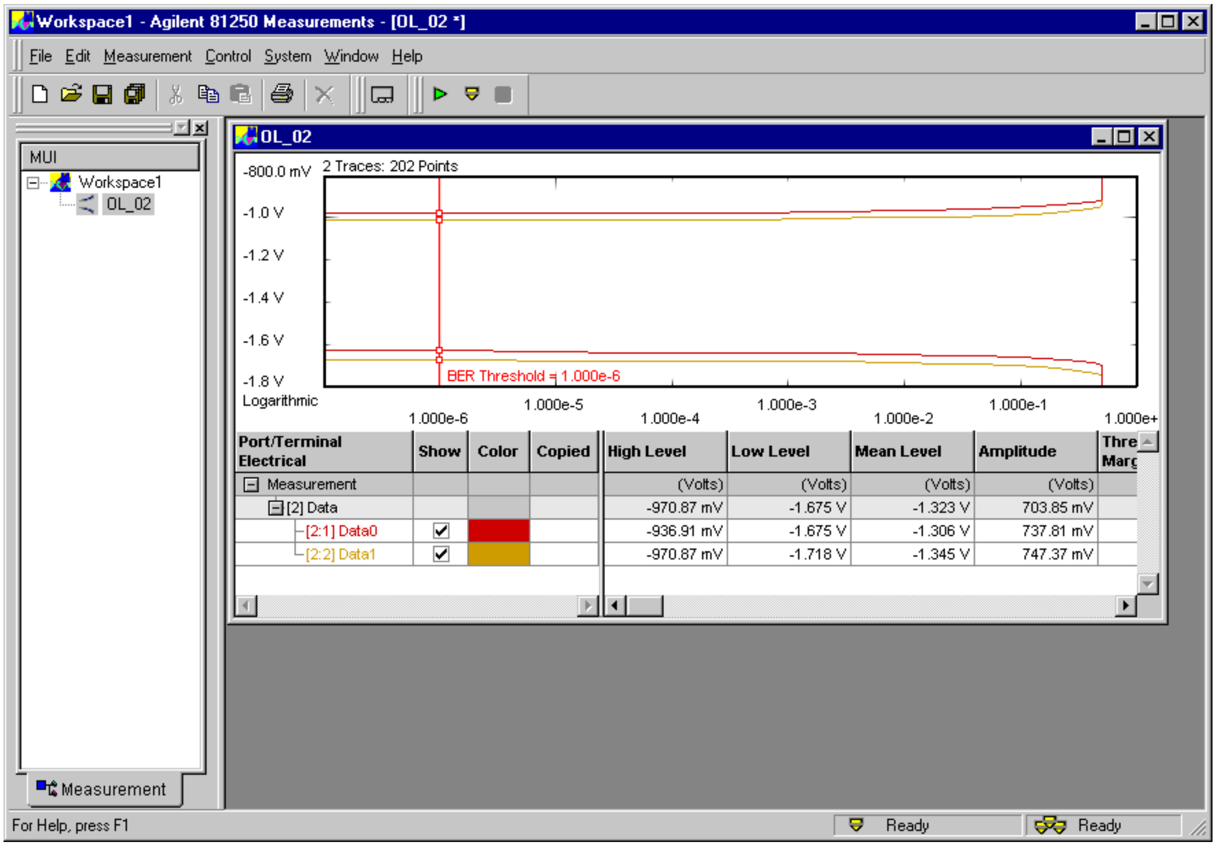
Note that we have also disabled the *Edge Resolution Optimization*.

8 Click *OK*. This terminates the *Properties* dialog. Now you can see how the workspace and the measurement are presented.



9 In the tool bar, click the Run button to execute the measurement.

The measurement is run, and the result window shows the bit error rates measured at 100 threshold levels from –1.8 V up to –800 mV.



By default, the traces of both terminals are displayed, together with the measured values.

You can hide a trace by clicking the terminal's checkbox in the *Show* column.

You can also change the trace colors by means of the *Color* boxes.

Improving the Output Level Display

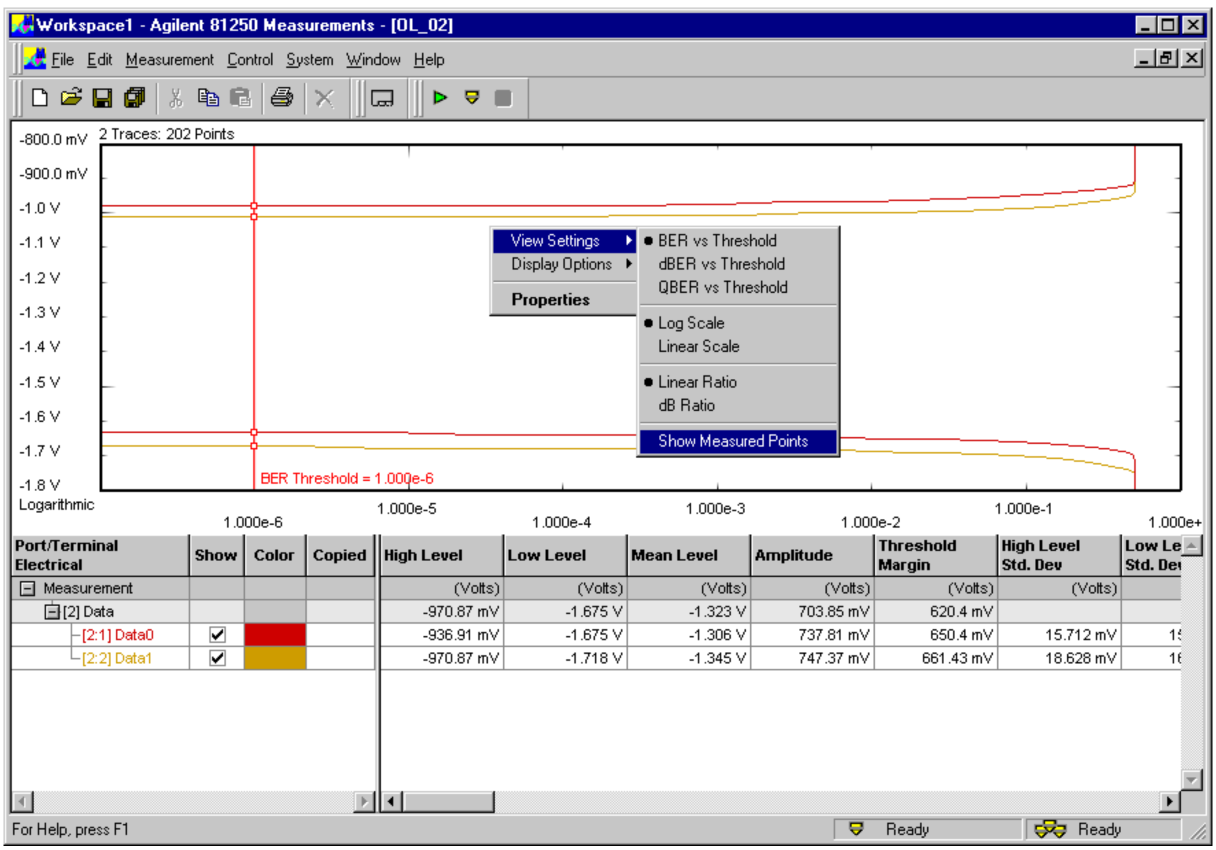
You may wish to see more details and to investigate the graph. This can be done from the *View* page of the *Properties* dialog or directly from the context menu of the graph. The latter method is very convenient and demonstrated here.

1 Close the Workspace window.

2 Enlarge the Measurement window.

3 Right-click the graphical area of the measurement window. This opens the context menu.

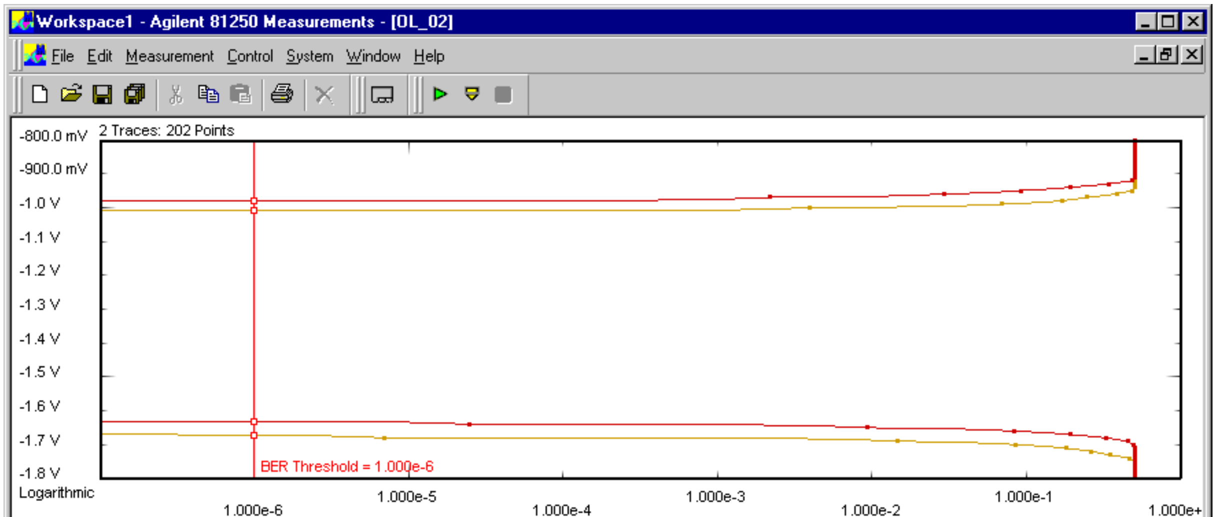
4 Choose *View Settings*.



NOTE The *View Settings* menu provides quick access to many functions that can also be accessed from the *View* page of the *Properties* dialog. See also *"How to Specify the View" on page 59*.

5 Select *Show Measured Points.*

This shows you the pairs of threshold vs. BER combinations that have been measured.



Port/Terminal Electrical	Show	Color	Copied	High Level	Low Level	Mean Level	Amplitude	Threshold Margin	High Level Std. Dev	Low Le... Std. De...
Measurement				(Volts)	(Volts)	(Volts)	(Volts)	(Volts)	(Volts)	
[2] Data				-970.87 mV	-1.675 V	-1.323 V	703.85 mV	620.4 mV		
[2:1] Data0	✓			-936.91 mV	-1.675 V	-1.306 V	737.81 mV	650.4 mV	15.712 mV	1...
[2:2] Data1	✓			-970.87 mV	-1.718 V	-1.345 V	747.37 mV	661.43 mV	18.628 mV	1...

We have not captured many points during this measurement, but it was quickly finished.

The headline of the graph tells us the number of data points included in the display: 202. That means, 101 points for each terminal. This corresponds to the chosen threshold resolution of 100 steps per Volt.

Consequently, neither the graphs nor the calculations are very precise. Actually, we have traded measurement precision against test time.

Changing the Output Level Properties

So far, we have set the focus on speed: 100 threshold levels and one million compared bits. You may wish to obtain more precise results.

1 Open the context menu of the result window (press the right-hand mouse button) and choose *Properties*.

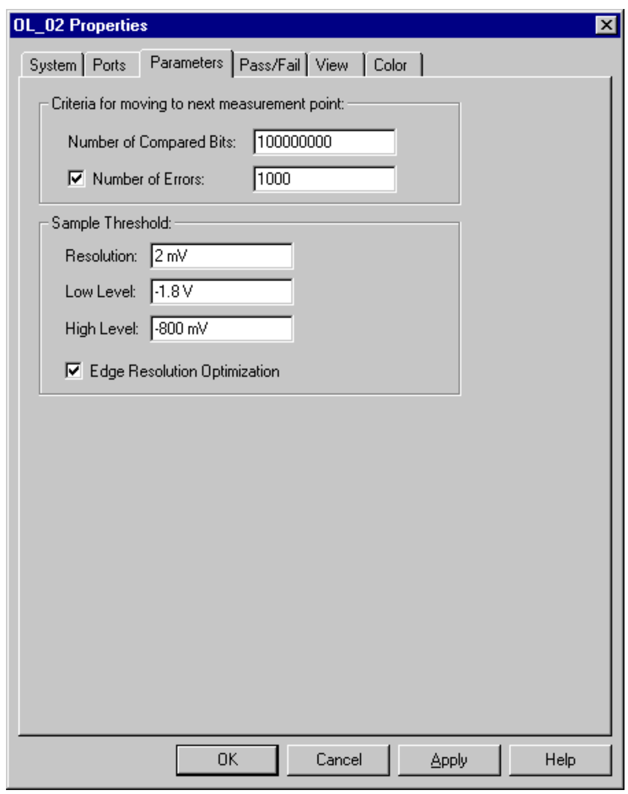
2 Click the *Parameters* tab.

3 Increase the *Number of Compared Bits* to 100,000,000

   Remember: One failure per 1 million bits yields a BER resolution of 10^{-6}. One failure per 100 million bits yields a BER resolution of 10^{-8}.

4 Decrease the *Resolution* (the threshold step size) to 2 mV.

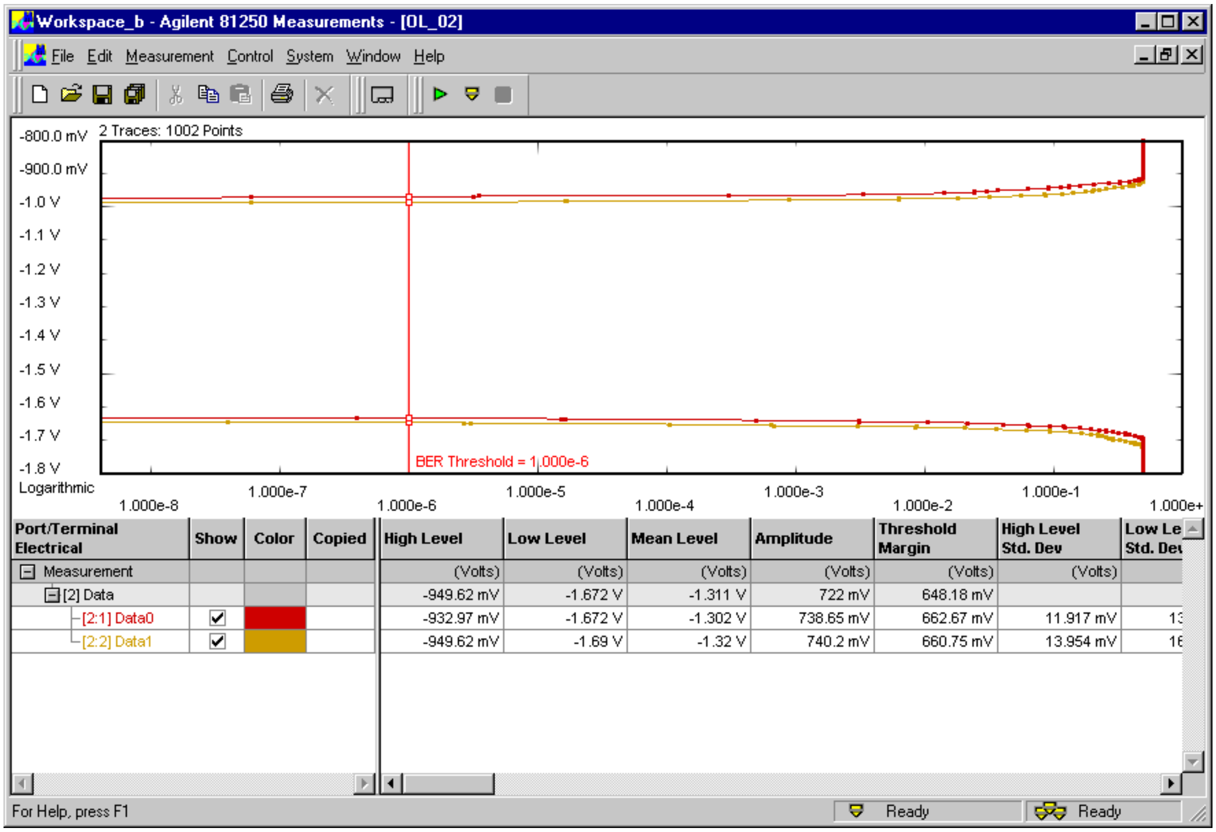
   This gives us 500 steps per Volt.



5 Click *OK*.

6 Click the Run button to repeat the measurement.

This measurement takes more time than the previous, but it is also much more precise.



You can use markers for analyzing the graph or open a zoom window for viewing the details. All this is described in *"Output Level Measurement Graphical Results" on page 28*.

When you move the *BER Threshold* bar with the mouse, you will see that some of the calculated values change. This is explained in *"Output Level Measurement Numerical Results" on page 36*.

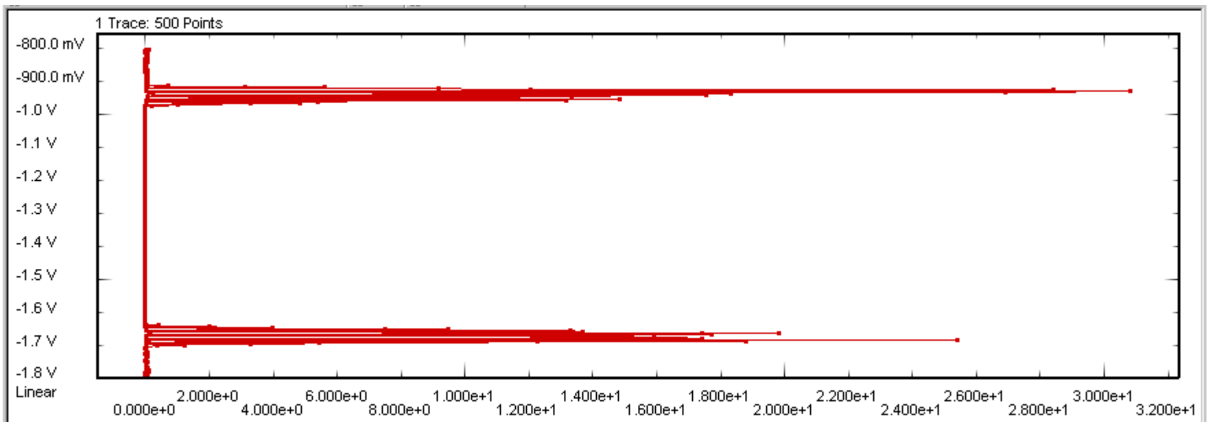
7 Open the context menu of the graph (click the right-hand mouse button). Choose *View Settings* and *dBER vs. Threshold*.

   This gives you another view of the measured data.

8 Open the context menu of the graph once more, select *View Settings*, and switch to *Linear Scale*.

   The data remains the same, but a linear scale makes it easier to see the distribution.

This graph shows you the absolute values of the derivative of the bit error rates over the thresholds (dBER/dThreshold). For the upper terminal in our example, this looks as shown below:



The graph provides a special marker that allows you to estimate the data distribution by approximating it by means of a Gaussian normal distribution.

More important: This graph *visualizes* the data that form the basis for the calculations of the level and noise values.

NOTE The Output Level measurement provides a third graphical display: the *QBER vs. Threshold* graph. This graph refers to the Q-factor calculations. We will not discuss it in this example.

For details on the Q-factor calculations see *"The QBER vs. Threshold Graph" on page 34* and *"Explanation of the Q-Factor Results" on page 39*.

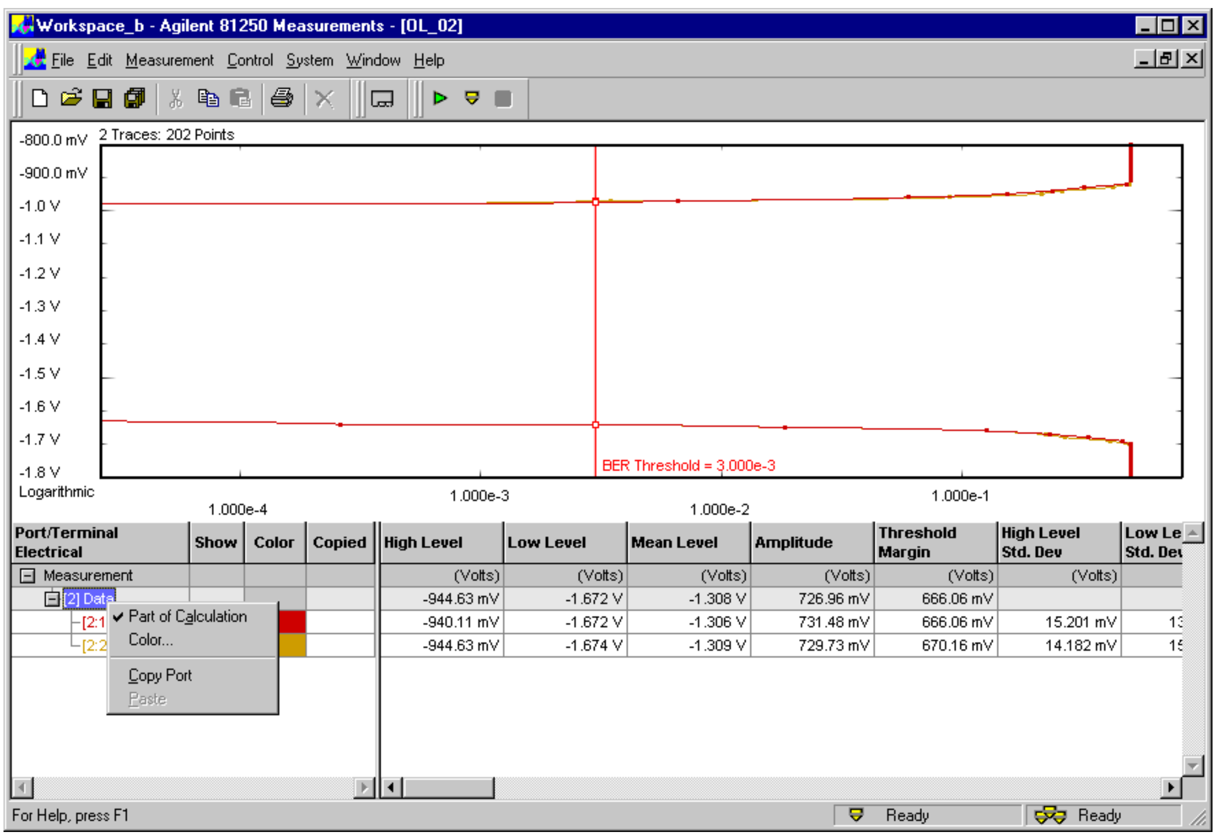
Comparing Output Level Measurement Results

If you intend to repeat a measurement, you may wish to preserve the current results for easy comparison. This can be done by copying the results of

- the whole measurement,
- a port with all of its terminals,
- a single terminal.

1 In the lower left-hand corner of the measurement window, right-click the measurement, port, or terminal.

This opens the corresponding context menu.



We have chosen the port in this example.

NOTE This menu allows you to disable or enable the calculation of port results.

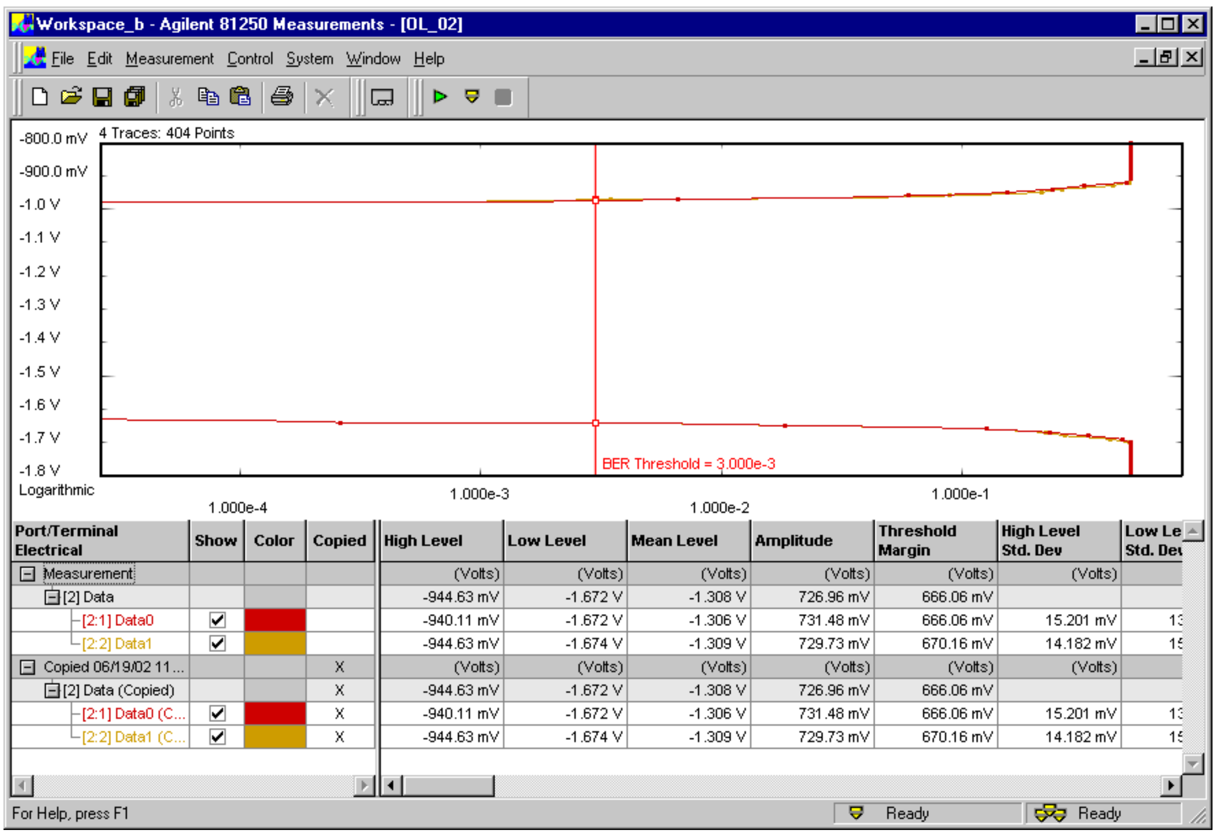
You can also assign a uniform color to all the terminals of the port. This takes effect in the graph and may be useful to separate between old and new traces.

2 Choose *Copy Port*.

This copies the results of the port and its terminals to the clipboard.

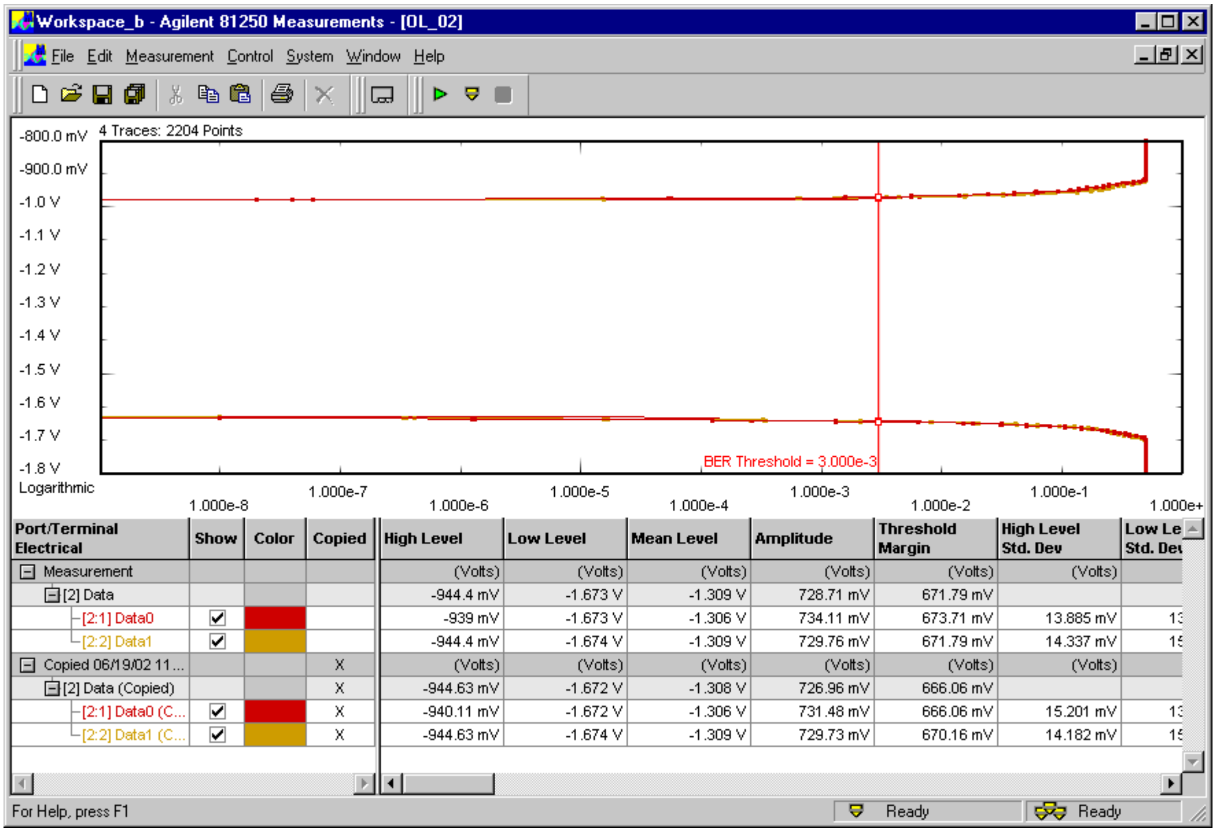
3 Open the context menu once more and choose *Paste*.

This inserts a copy of the chosen measurement, port, or terminal results. It looks as shown below:



4 Repeat the measurement.

You can now directly compare the graphical and numerical results.



For the new measurement, we have increased the number of compared bits and decreased the width of the threshold steps. You can see how this affects the results.

Basics of the Output Level Measurement

In this section, you find the following information:

- For the preconditions that have to be met to run the measurement, refer to *"Prerequisites for Output Level Measurements" on page 27*.
- For the explanations of the graphical measurement results, refer to *"Output Level Measurement Graphical Results" on page 28*.
- For the explanations of the numerical measurement results, refer to *"Output Level Measurement Numerical Results" on page 36*.

Prerequisites for Output Level Measurements

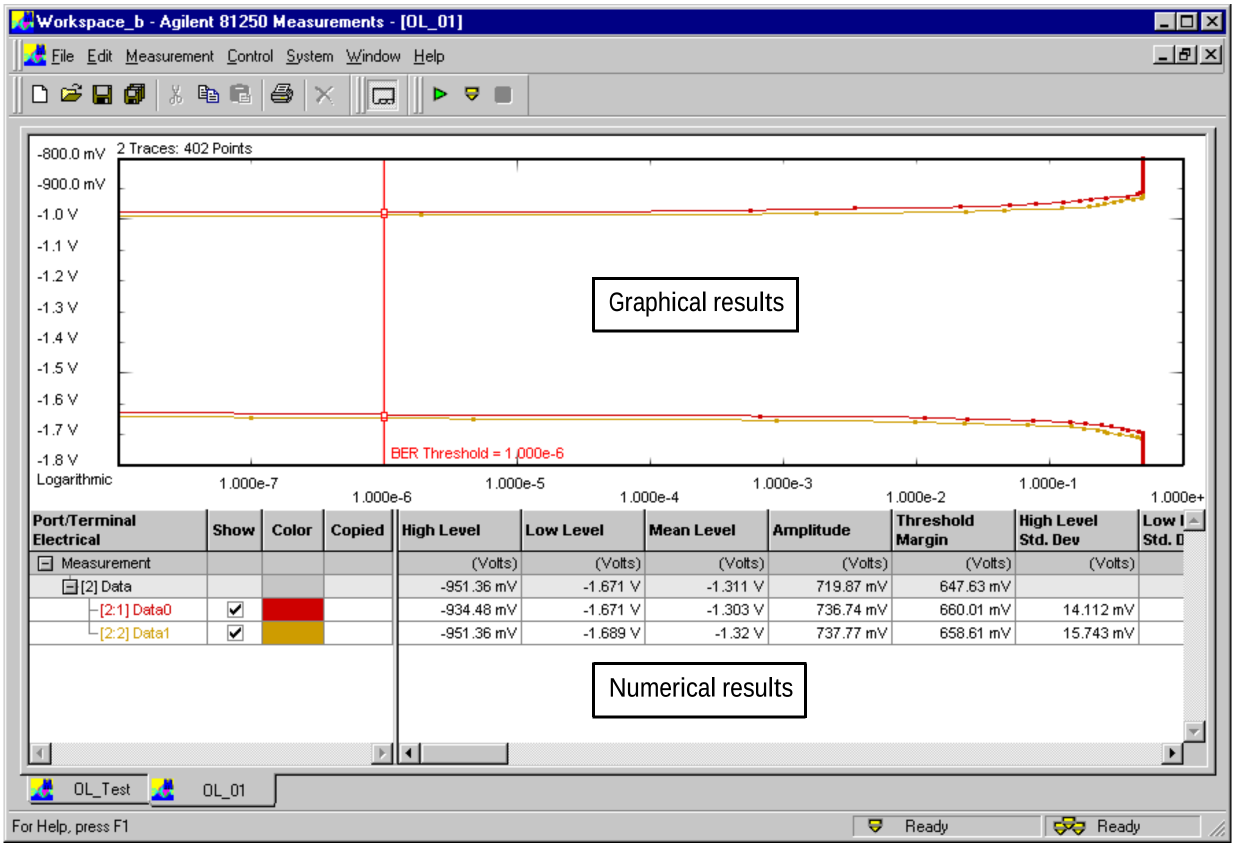
In order to perform Output Level measurements, the following prerequisites have to be met in addition to the global ones (see *Prerequisites* in the *Framework User Guide*):

- The analyzer *Frontend Modes* have to be "single ended normal" or "single ended complement", or the *Analyzed Input* has to be set to "input" or "~input". Output Level measurements require threshold voltages and can therefore not be measured in differential mode.
- The analyzers have to be synchronized to the incoming data stream
  - either manually (specify a valid start delay)

    or
  - by automatic analyzer sampling point adjustment (Automatic Bit Synchronization or Automatic Delay Alignment).
- If automatic analyzer sampling point adjustment is used, the phase delay verniers of the analyzers have to be in zero position.

Output Level Measurement Graphical Results

The Output Level measurement software performs a measurement and returns the results graphically and numerically.



The following sections explain these results.

NOTE Under certain circumstances, some numerical results are not available. This is indicated by <*invalid*> or <*not applicable*> in the numerical results table below the measurement graphic.

- <*invalid*> indicates that the value could not be calculated. This is the case, for example, for threshold margin, when the BER threshold is set to high values and does not intersect with the measured curve.

- <*not applicable*> indicates that the value could be calculated, is however not shown because quality criteria are not met. This is the case, for example, for Q-Factor results, when the r^2 value of one or both edges is <0.75. Even thought Q-Factor values can be calculated in this case, they are not shown because confidence in the results is so low.

For details on the graphical results see:

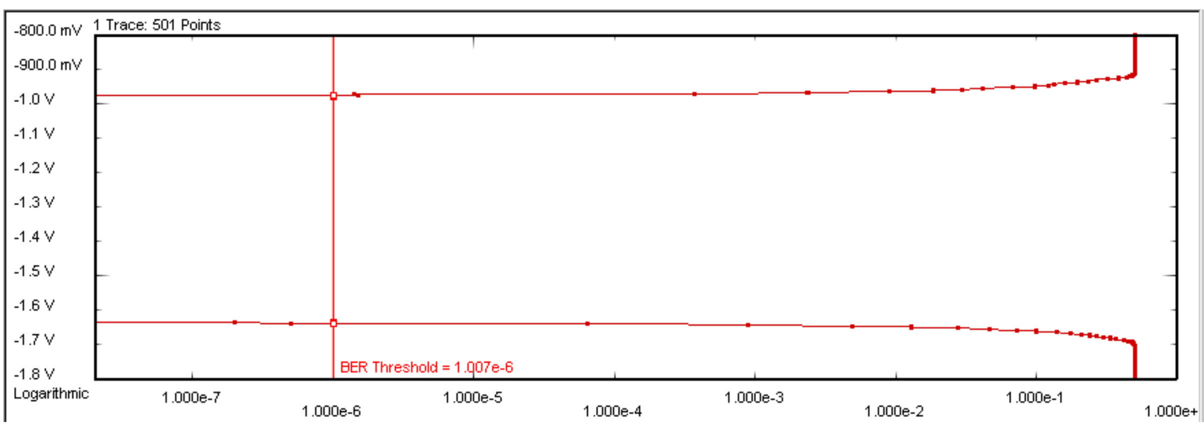
- *"The BER vs. Threshold Graph" on page 29*
- *"The dBER vs. Threshold Graph" on page 31*
- *"The QBER vs. Threshold Graph" on page 34*

For the numerical results see

- *"Output Level Measurement Numerical Results" on page 36*

The BER vs. Threshold Graph

This graph shows the relationship between the analyzer decision threshold and the measured BER.



The BER considers all errors. It is calculated as:

$$BER_{AllErrors} = \frac{(\sum Error1s + \sum Error0s)}{(total\ \#\ of\ Bits)}$$

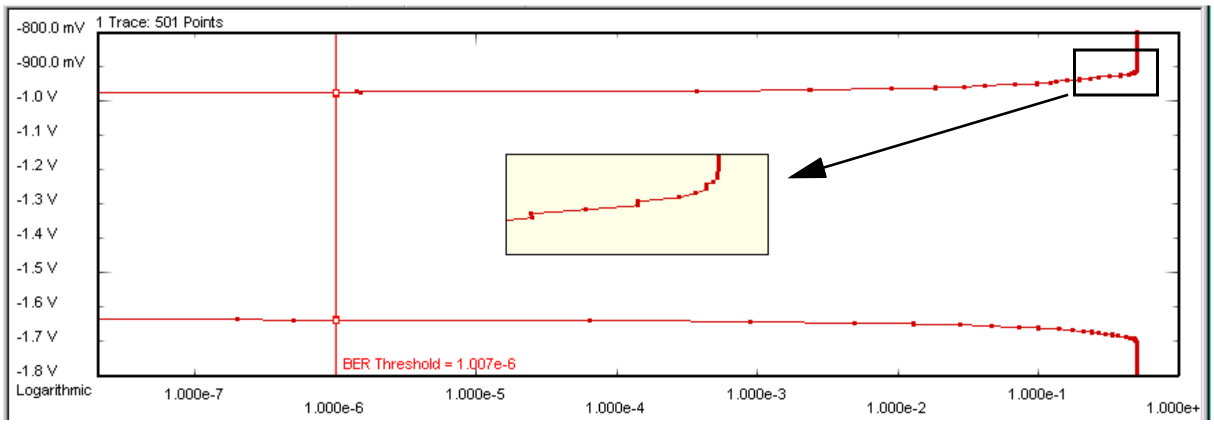
Measured points display

In the figure above and in the following figures, the display of the measured points has been enabled. This feature allows you to identify the pairs of threshold level and BER that have been measured. The total number of measured points contained in the graph is indicated on the top of the graphical window.

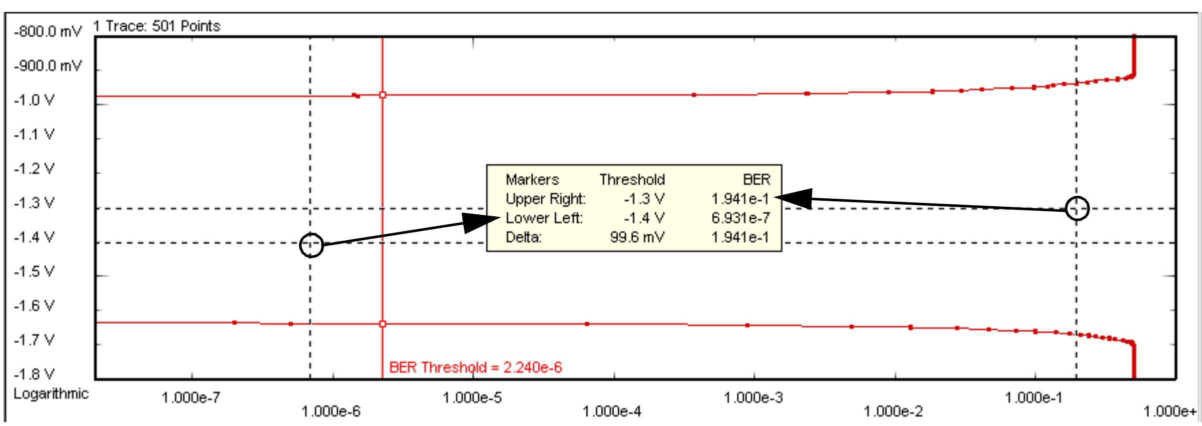
Scales The vertical scale is determined by the measurement parameters. The horizontal scale can be toggled between logarithmic and linear.

BER Threshold The *BER Threshold* can be moved with the mouse. It can also be set on the *View* page of the *Properties* dialog. Its position has an impact on the calculated values of *Threshold Margin*, *Noise*, and all the values associated with the *Q-factor*.

Zoom The zoom window makes it possible to study the details.



Markers Markers can be used for analyzing the graph. They are formed by two vertical and two horizontal dotted lines that can be moved with the mouse.

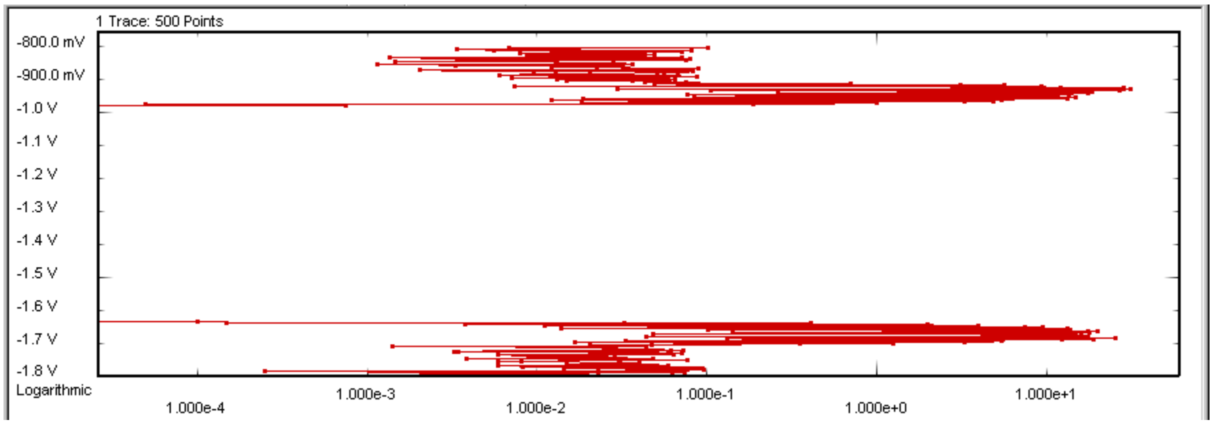


The marker readout informs you about the positions of the upper right-hand and lower left-hand intersections and their deltas.

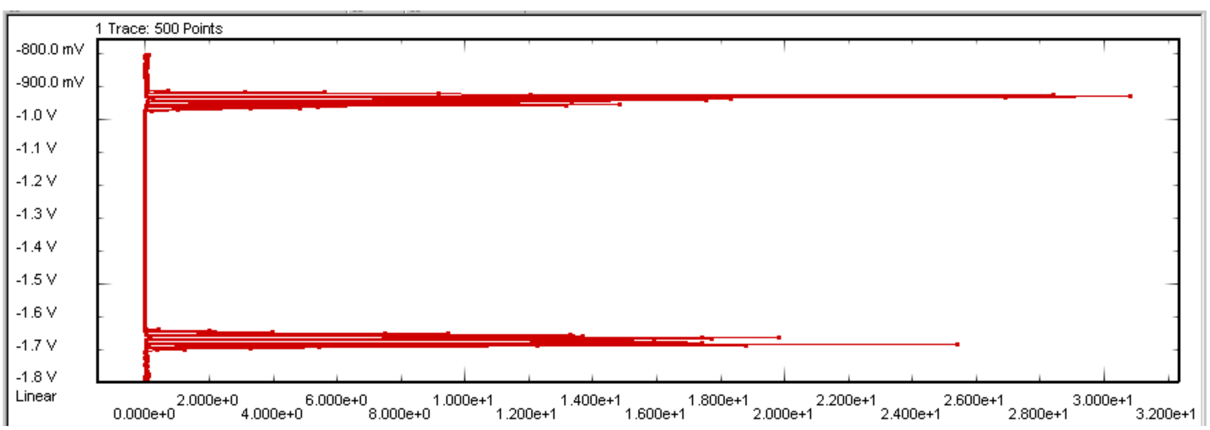
The dBER vs. Threshold Graph

This graph shows the relationship between the analyzer decision threshold and the absolute values of the derivative of the bit error rate (dBER/dTh).

In logarithmic scale, it looks as shown below:



A linear scale reveals the distribution more clearly:



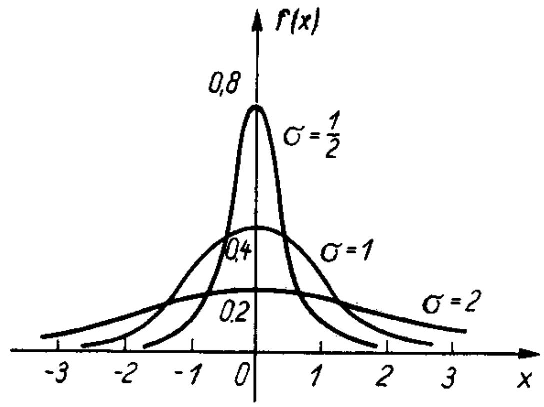
This distribution can often be approximated by a Gaussian normal distribution.

Gaussian normal distribution

The distribution of random values is called normal if it can be described by the following formula:

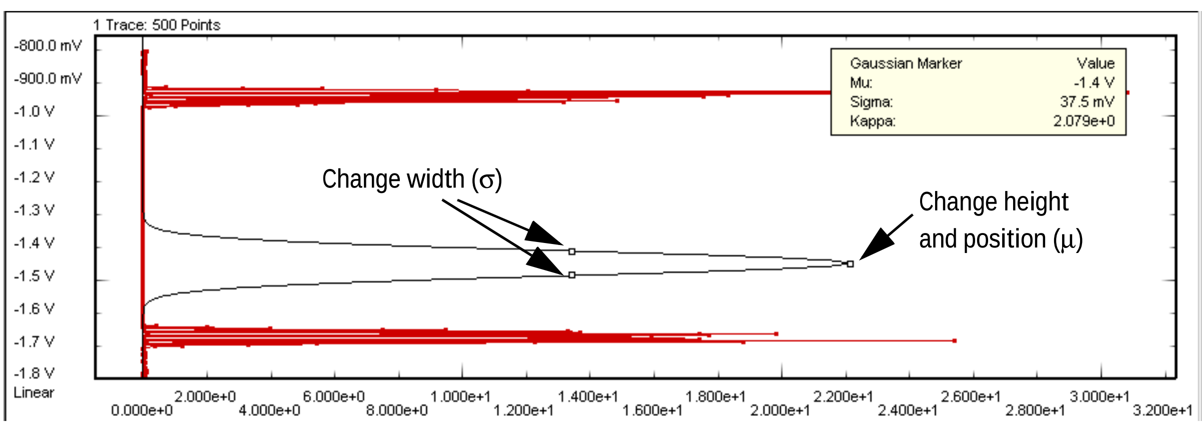
$$f(x) = \frac{1}{\sigma\sqrt{2\pi}} e^{-\frac{(x-\mu)^2}{2\sigma^2}}$$

This formula describes a bell shaped Gauss curve. If μ is zero and σ varied, you would get the curves illustrated in the figure below:



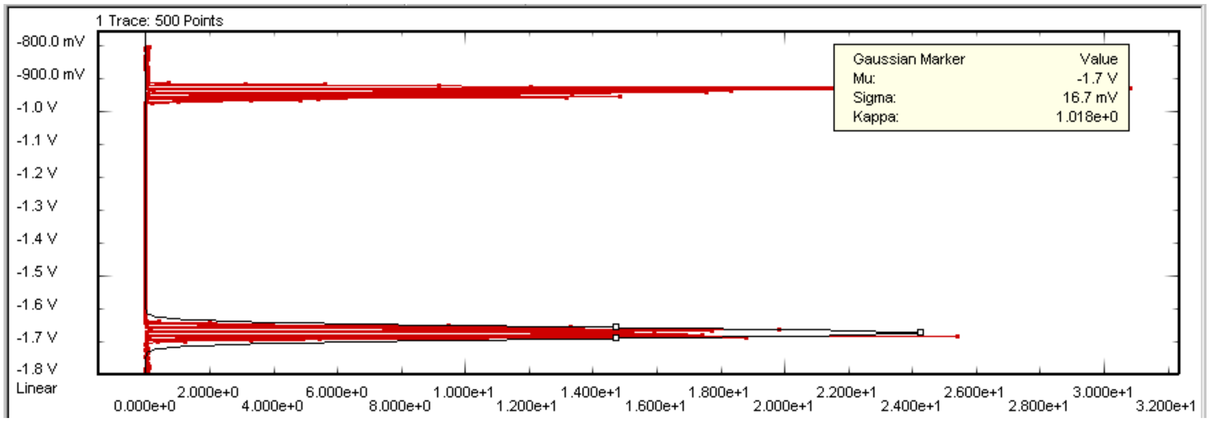
The shape and position of a normal distribution can be specified in terms of two parameters: μ and σ. The parameter μ is the mean, the parameter σ is the standard deviation.

Marker The Gaussian marker allows you to make an approximation.



The marker has three handles that can be dragged with the mouse: two for adjusting its width, one for changing its height and position.

After adjusting the marker to the curve, you can read the calculated values.

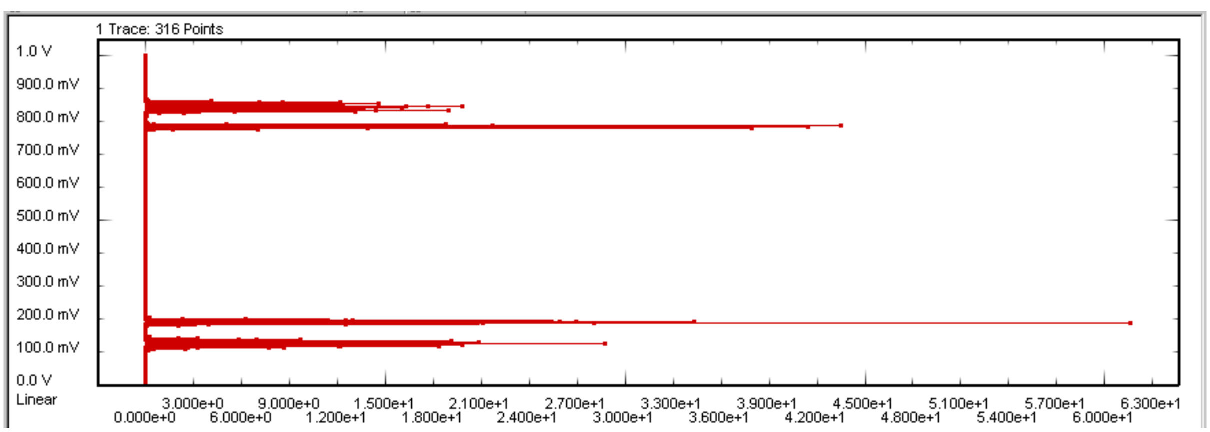


The marker readout provides the following information:

Parameter	Symbol	Meaning
Mu	μ	Mean. The position of the marker center on the vertical threshold scale.
Sigma	σ	Standard deviation. The RMS value of the marked area.
Kappa	κ	Linear scaling factor.

In the example above, Mu and Sigma will be the same as the Level and Standard Deviation results calculated by the measurement.

But your dBER distribution may also look like this:



The measurement will calculate the Level and Standard Deviation results from all data points. The marker allows you to measure the μ and σ of the individual peaks.

The QBER vs. Threshold Graph

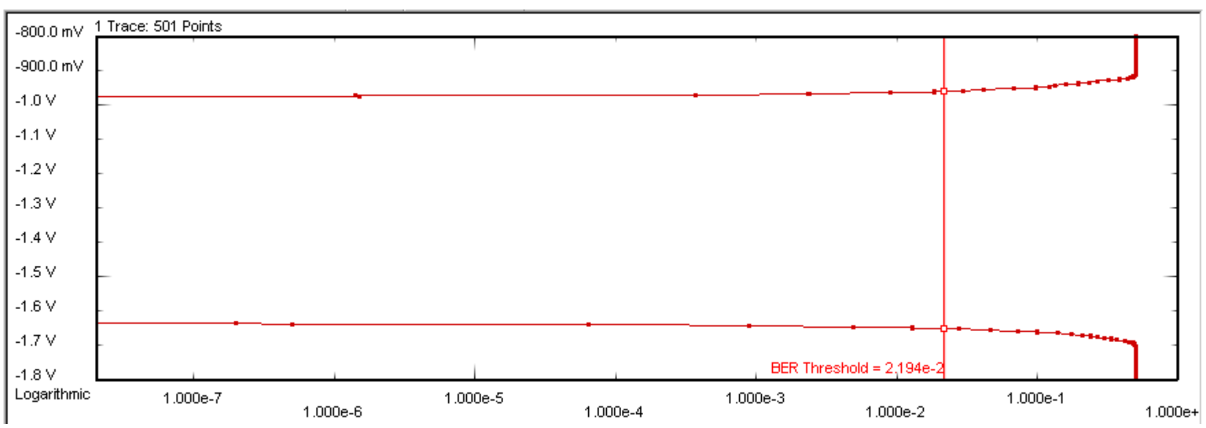
This graph shows the extrapolation of the optimum Q-factor and the optimum threshold level from a limited number of measured points.

The measured data points to be used for the calculation have to be within a contiguous BER range. This range is defined by specifying a lower and an upper BER threshold.

Both thresholds can be set on the *View* page of the *Properties* dialog.

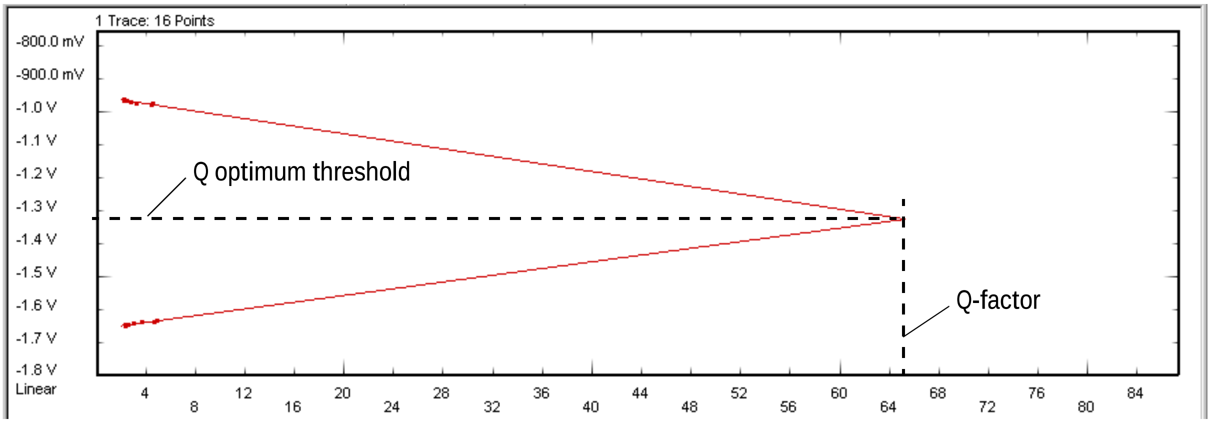
By default, the lower BER threshold (*Min BER for Q*) is zero. The upper threshold is identical with the *BER Threshold* shown in the BER vs. Threshold graph. In this graph, it can also be moved with the mouse.

To enable the Q-factor calculation, the range between the two thresholds must contain more than two measured points.



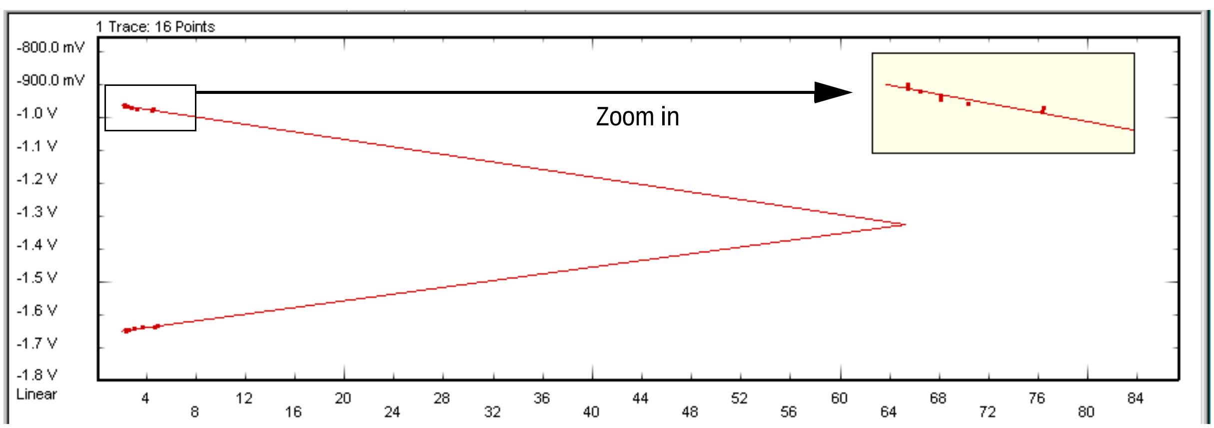
In the figure above, we have moved the *BER Threshold* to the right until the BER range down to zero includes some measured points for each of the two levels.

From these points, the following QBER vs. Threshold graph is generated:



This graph illustrates the calculation of the *Q-factor* (65 in the figure above) and makes the calculation reproducible. For details see *"Explanation of the Q-Factor Results" on page 39*.

Zoom The zoom function shows you how the best fit line is drawn through the converted data points.



Scales The vertical scale is determined by the measurement parameters. The horizontal Q-factor scale is linear.

Markers Markers can be used for analyzing the graph. These are the same types of markers as are used in the BER vs. Threshold graph.

Output Level Measurement Numerical Results

The result parameters are divided into three groups:

- Levels
- Noise results
- Q-factor results

The measured and calculated values of all three groups are displayed in numerical form below the graphs.

The result parameters are summarized in the following table:

Group	Parameter Name (Optical)	Parameter Name (Electrical)	Pass / Fail
Levels	One Level	High Level	min / max
	Zero Level	Low Level	min / max
	Mean Level	Mean Level	min / max
	Optical Modulation Amplitude	Amplitude	min / max
	Threshold Margin	Threshold Margin	min
	Extinction Ratio	N / A	min
Noise	One Level Std.Dev	High Level Std.Dev	
	Zero Level Std.Dev	Low Level Std.Dev	
	Peak Peak Noise	Peak Peak Noise	max
	Signal / Noise Ratio (RMS)	Signal / Noise Ratio (RMS)	min
	Signal / Noise Ratio (Peak Peak)	Signal / Noise Ratio (Peak Peak)	min
Q-factor	Q Factor	Q Factor	min
	Q Optimum Threshold	Q Optimum Threshold	min / max
	Q Residual BER	Q Residual BER	max
	Q One Level	Q High Level	
	Q One Level Std.Dev	Q High Level Std.Dev	
	Q One Level Nr. Points	Q High Level Nr. Points	
	Q One Level R^2	Q High Level R^2	
	Q Zero Level	Q Low Level	
	Q Zero Level Std.Dev	Q Low Level Std.Dev	
	Q Zero Level Nr. Points	Q Low Level Nr. Points	
	Q Zero Level R^2	Q Low Level R^2	

For many of these parameters, pass/fail limits can be set, as indicated in the previous table.

For details see

- *"Explanation of the Level Results" on page 37*
- *"Explanation of the Noise Results" on page 38*
- *"Explanation of the Q-Factor Results" on page 39*

Explanation of the Level Results

The level parameters are defined as follows:

Parameter	Description
One Level / High Level	The One Level for a **terminal** is the mean of the upper dBER/dTh distribution. It is calculated as: $$Mean = \frac{\sum (dBer \cdot threshold)}{\sum dBer}$$ The One Level for a **port** is the minimum of all One Levels of all terminals in this port.
Zero Level / Low Level	The Zero Level for a **terminal** is the mean of the lower dBER/dTh distribution. It is calculated as: $$Mean = \frac{\sum (dBer \cdot threshold)}{\sum dBer}$$ The Zero Level for a **port** is the maximum of all Zero Levels of all terminals in this port.
Mean Level	The Mean Level for a **terminal** is the middle between its One and Zero Levels, calculated as: $$Mean\ Level = \frac{ZeroLevel + OneLevel}{2}$$ The Mean Level for a **port** is the sum of the port's One and Zero Levels divided by two.
Optical Modulation Amplitude / Amplitude	The Optical Modulation Amplitude or Amplitude for a **terminal** is the difference between its One and Zero Levels. The Optical Modulation Amplitude or Amplitude for a **port** is the difference between the port's One and Zero Levels.
Threshold Margin	The Threshold Margin for a **terminal** is the distance between the upper and the lower BER curves at the position given by the *BER Threshold* setting. The Threshold Margin for a **port** is the minimum of the terminals' Threshold Margins.
Extinction Ratio	The Extinction Ratio is only available for optical measurements. The Extinction Ratio for a **terminal** is calculated as its One Level divided by Zero Level. The Extinction Ratio for a **port** is the port's One Level divided by Zero Level.

Explanation of the Noise Results

The noise parameters are not available for ports. They are defined as follows:

Parameter	Description
One Level Std. Dev. / High Level Std. Dev.	The Standard Deviations are derived from the dBER/dTh histogram. The One Level Standard Deviation is calculated as: $StdDev = \sqrt{\frac{\sum((threshold - Mean)^2 \cdot dBer)}{\sum dBer}}$ where *Mean* is the One or High Level of the terminal.
Zero Level Std. Dev. / Low Level Std. Dev.	The Zero Level Standard Deviation is calculated as: $StdDev = \sqrt{\frac{\sum((threshold - Mean)^2 \cdot dBer)}{\sum dBer}}$ where *Mean* is the Zero or Low Level of the terminal.
Peak Peak Noise	The peak-to-peak Noise is calculated as: $Peak\ Peak\ Noise = OneLevel - ZeroLevel - Threshold\ Margin$ Note that the Threshold Margin depends on the position of the *BER Threshold*.
Signal/Noise Ratio (RMS)	The RMS Signal-to-Noise Ratio is calculated as: $SNR(RMS) = \frac{Mean\ 1 - Mean\ 0}{StdDev\ 1 + StdDev\ 0}$ where *Mean 1* = One Level, and *Mean 0* = Zero Level.
Signal/Noise Ratio (Peak Peak)	The peak-to-peak Signal-to-Noise Ratio is calculated as $SNR(PeakPeak) = \frac{Mean\ 1 - Mean\ 0}{PeakPeakNoise}$ where *Mean 1* = One Level, and *Mean 0* = Zero Level. Note that the Peak Peak Noise depends on the position of the *BER Threshold*.

Explanation of the Q-Factor Results

The variable decision threshold method used by the Output Level measurement makes it possible to determine the Q-factor of a signal.

NOTE The Q-factor method and the related calculations have been published under “Margin Measurements in Optical Amplifier Systems” by Neal S. Bergano, F. W. Kerfoot, and C. R. Davidson in IEEE Photonics Technology Letters, Vol. 5, No. 3, March 1993.

Mathematical Background

Bit errors are caused by noise, and the Q-factor describes the signal-to-noise ratio at the decision circuit.

It is possible to calculate the Q-factor from a limited number of measured BER vs. threshold data points. It is also possible to calculate expected bit error rates from the Q-factor. This is a method for predicting very low bit error rates (typically below 10^{-11}) that would take a long time to measure.

The Q-factor is calculated as:

$$Q = \frac{\mu_1 - \mu_0}{\sigma_1 + \sigma_0}$$

where $\mu_{1,0}$ is the mean level of the 1 and 0 rails, respectively, and $\sigma_{1,0}$ is the standard deviation of the noise distribution on the 1 and 0 rails.

The $\mu_{1,0}$ and $\sigma_{1,0}$ values are calculated from a selected range of data points. This calculation is correct if the noise distribution has Gaussian characteristics. Then, the bit error rate can be expressed as:

$$\mathrm{BER}(D) = \frac{1}{2}\left\{\mathrm{erfc}\left(\frac{|\mu_1 - D|}{\sigma_1}\right) + \mathrm{erfc}\left(\frac{|\mu_0 - D|}{\sigma_0}\right)\right\}$$

where D is the decision threshold, $\mu_{1,0}$ and $\sigma_{1,0}$ are the mean and standard deviation of the 1 and 0 rails, and erfc (x) is the complementary error function.

This formula is the sum of two terms. It considers the probabilities of deciding that a “0” has been received when a “1” was sent, and that a “1” has been received when a “0” was sent.

For the following calculations, the assumption is made that the BER is dominated by only one of the terms noted above, depending on whether the threshold is closer to the 1 or 0 rail.

For the complementary error function

$$erfc(x) = \frac{1}{\sqrt{2\pi}} \int_x^{\infty} e^{-\beta^2/2} d\beta \approx \frac{1}{x\sqrt{2\pi}} e^{-x^2/2}$$

an inverse logarithmic approximation exists:

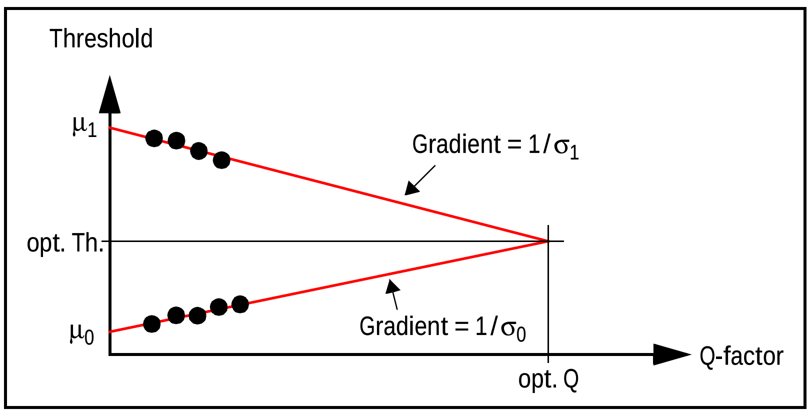
$$\left[Log\left\{ \frac{1}{2} erfc(x) \right\} \right]^{-1} \approx 1.192 - 0.6681x - 0.0162\,x^2$$

where x = Log(BER).

This function, applied to the high level and low level data points, yields new threshold vs. value combinations.

In the area of low BER (typically below 10^{-4}), these new data pairs should fit to two straight lines, although a couple of assumptions and approximations have been made.

To determine the gradient and offset of these lines, a linear regression is performed. This is illustrated in the figure below.



A straight line can be expressed as:

$$Y = A + BX$$

where Y is the inverse error function of BER, and X is D, the decision threshold.

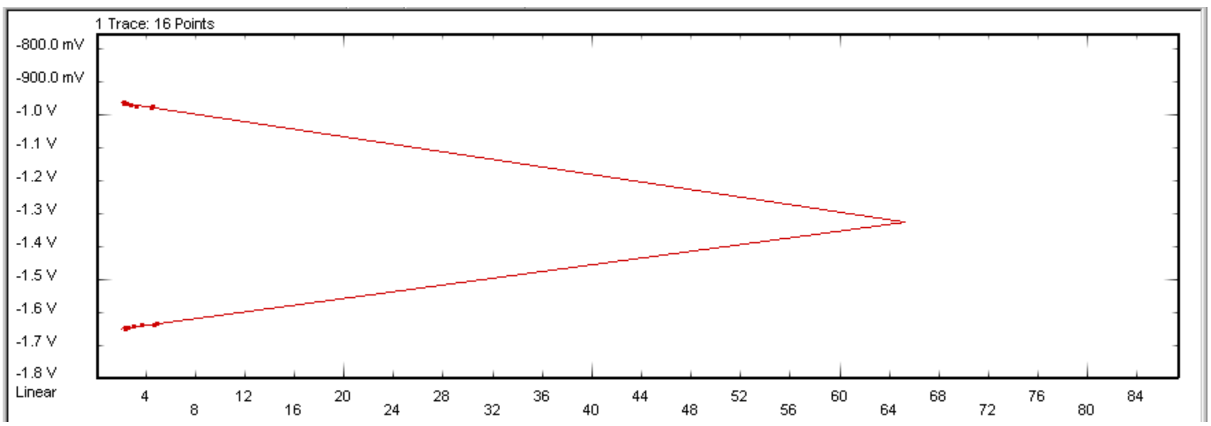
The following calculations are performed for the high and low level data:

$$B = \frac{\Sigma XY - \frac{(\Sigma X)(\Sigma Y)}{n}}{\Sigma X^2 - \frac{(\Sigma X)^2}{n}}$$

$$A = \frac{\Sigma Y}{n} - B\frac{\Sigma X}{n}$$

where n is the number of respective data points.

The results of the linear regression are displayed in the QBER vs. Threshold graph.



This graph shows two straight lines. The intersection of these lines marks the Q-factor and the Q optimum Threshold.

Mathematically, the standard deviation and mean values are calculated as:

$$\sigma = \left| -\frac{1}{B} \right|$$

$$\mu = \frac{-A}{B}$$

This calculation leads to the values of $\mu_{1,0}$ and $\sigma_{1,0}$.

Calculated Q-Parameters

The numerical Q-parameters are only available for terminals, not for ports. They are defined as follows:

Parameter	Description
Q Factor	The Q-factor is calculated as: $$Q = \frac{\mu_1 - \mu_0}{\sigma_1 + \sigma_0}$$ where $\mu_{1,0}$ is the mean level of the 1 and 0 rails, respectively, and $\sigma_{1,0}$ is the standard deviation of the noise distribution on the 1 and 0 rails.
Q Optimum Threshold	The Q Optimum Decision Threshold is calculated as: $$\text{Optimum Decision Threshold} = \frac{\sigma_0\mu_1 + \sigma_1\mu_0}{\sigma_1 + \sigma_0}$$
Q Residual BER	The Q Residual BER is the expected BER at the Optimum Decision Threshold. It is calculated as: $$BER = \frac{e^{-(Q^2/2)}}{Q_{opt}\sqrt{2\pi}}$$ Numbers below 1e–255 are expressed as zero.
Q One Level / Q High Level	The Q One Level is the mean, calculated from the linear regression curve for the high level data: $$\mu = \frac{-A}{B}$$ (See the explanations above the table)
Q One Level Std.Dev / Q High Level Std.Dev	The Q One Level Standard Deviation is the Sigma, calculated from the linear regression curve for the high level data: $$\sigma = \left\| -\frac{1}{B} \right\|$$ (See the explanations above the table)
Q One Level Nr. Points / Q High Level Nr. Points	This is the number of data points used for the calculation of the Q One Level values. It depends on the setting of the *BER Threshold* and also on the setting of the *Min BER for Q* parameter. The minimum for calculating Q-factor values is two points. It is recommended to use more than 5 points.

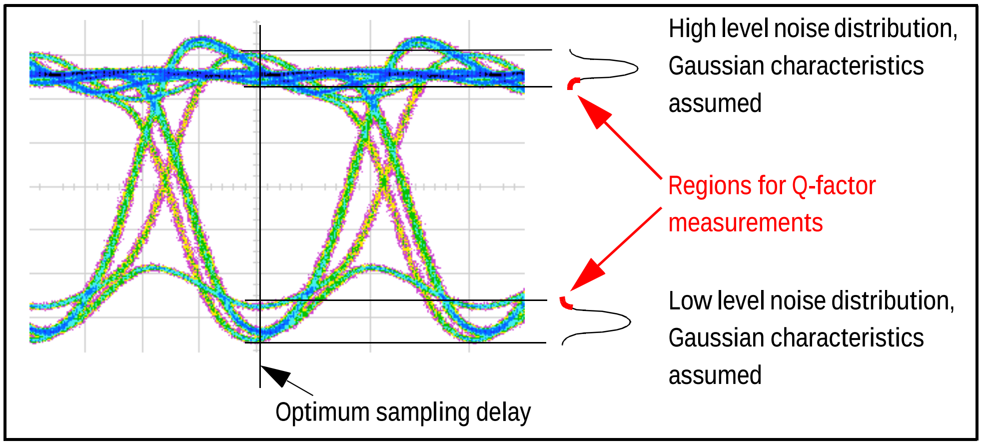
Parameter	**Description**
Q One Level R^2 / Q High Level R^2	The R^2 parameter is an indicator that shows how well the converted data points fit to the straight line. It is calculated as: $$R^2 = \frac{\left(\Sigma XY - \frac{(\Sigma X)(\Sigma Y)}{n}\right)^2}{\left(\Sigma X^2 - \frac{(\Sigma X)^2}{n}\right)\left(\Sigma Y^2 - \frac{(\Sigma Y)^2}{n}\right)}$$ (See the explanations above the table) The R^2 parameter should be examined before trusting the Q-values. Its maximum value is 1.0. It must be seen in conjunction with the number of data points. For example: Two data points always fit perfectly well, but the resulting Q-factor calculations are not reliable. On the other hand, 50 data points may reveal a poor R^2 value. This tells you that the linearization is prone to errors. If the R^2 value falls below 0.75, the Q-factor calculations are not applicable.
Q Zero Level / Q Low Level	The Q Zero Level is the mean, calculated from the linear regression curve for the low level data: $$\mu = \frac{-A}{B}$$ (See the explanations above the table)
Q Zero Level Std.Dev / Q Low Level Std.Dev	The Q Zero Level Standard Deviation is the Sigma, calculated from the linear regression curve for the low level data: $$\sigma = \left\| - \frac{1}{B} \right\|$$ (See the explanations above the table)
Q Zero Level Nr. Points / Q Low Level Nr. Points	This is the number of data points used for the calculation of the Q Zero Level values. It depends on the setting of the *BER Threshold* and also on the setting of the *Min BER for Q* parameter. The minimum for calculating Q-factor values is two points. It is recommended to include more than 5 points.
Q Zero Level R^2 / Q Low Level R^2	See the definition of “Q One Level R^2”.

A Few Notes on the Q-Results

You can specify the range of data points used for these calculations by means of the *Min BER for Q* and *BER Threshold* parameters (see also *"How to Specify the View" on page 59*).

Use of the Q-factor calculations

For example, you can calculate the Q-factor from relatively few data points with measured bit error rates between 1e–10 and 1e–5. The calculation tells you the optimum decision threshold and also the BER expected when the analyzer uses this threshold.



To measure such small bit error rates, you have to compare an adequate number of bits. Depending on the DUT characteristics, you may also have to use a very fine step size for the threshold variation.

When you are testing a device, it is generally not very useful to compare the Q-values with the directly measured values. The methods differ and serve different purposes.

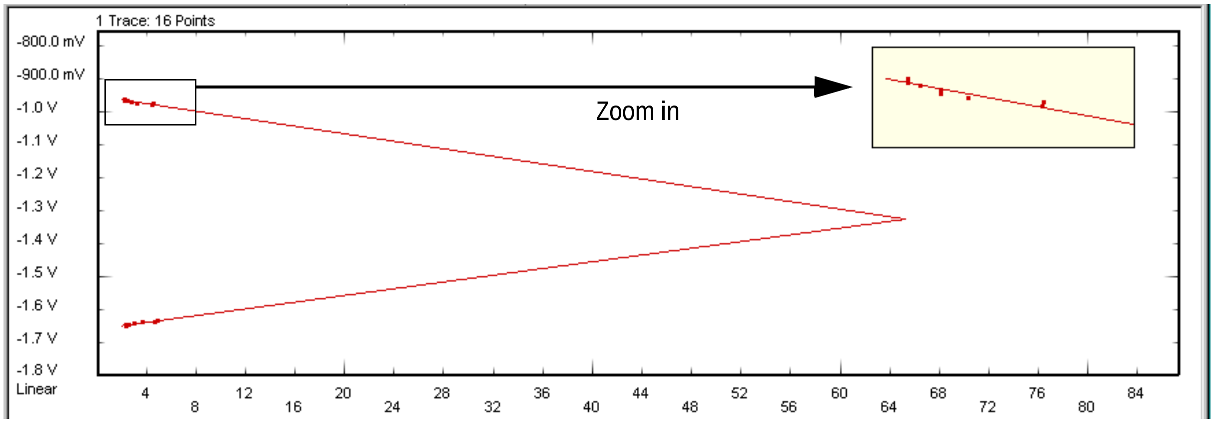
Comparison of the results

On the other hand, such a comparison may make it easier to understand the dependencies.

If you set the *BER Threshold* to a position that gives you only a few data points, you will find:

- The Q-factor is relatively high.
- The R^2 values are excellent (greater than 0.95).
- The mean levels and standard deviations returned by the Q-factor calculations differ from the measured values.

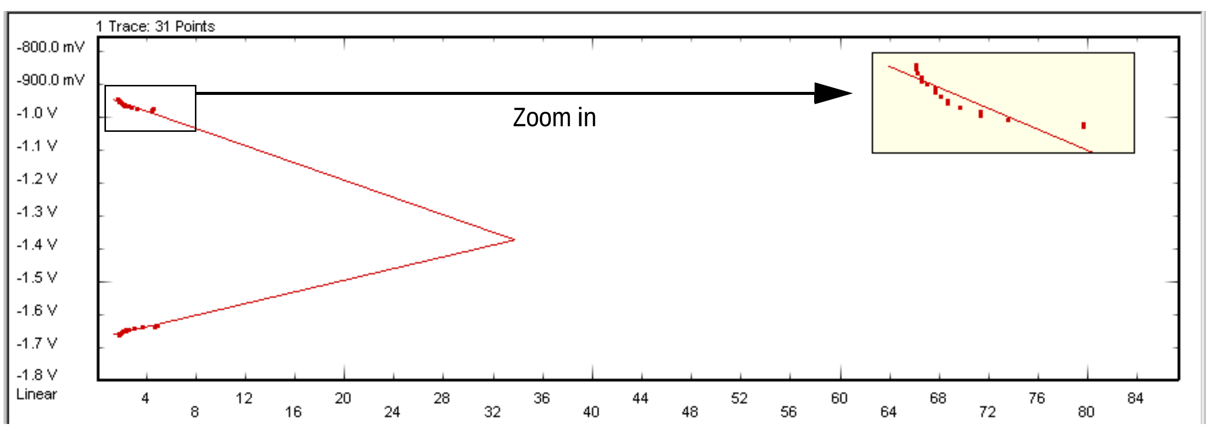
The QBER vs. Threshold graph may look as shown below:



If you increase the *BER Threshold* to include more points, you will find:

- The mean levels and standard deviations returned by the Q-factor calculations approach the measured values.
- The Q-factor decreases.
- The R^2 values deteriorate.

The latter is caused by increasing nonlinearity. This can be inspected in the QBER vs. Threshold graph.



NOTE The Q-factor calculations are disabled and flagged as “not applicable” if the R^2 value falls below 0.75.

The R^2 value can also be seen as an indicator of how well the noise distribution fits to Gaussian shape. It will not fit, for example, if the received signal is dominated by cross-talk or modal noise.

Setting the Properties of an Output Level Measurement

Before you can run a new Output Level measurement you have to set the required parameters on the measurement's *Properties* pages

When you create a new measurement, the *Properties* dialog will be automatically displayed.

To change the parameters of an existing measurement, choose *Measurement – Properties* from the menu bar. Or click the right mouse button and choose *Properties* from the context menu.

NOTE If you change the measurement settings after the measurement has been run, please note:

- Changes on the *View* and *Pass/Fail* pages have only an impact on the display of the results. There is no need to repeat the measurement.
- Changes on the *System*, *Ports*, and *Parameters* pages only take effect when you repeat the measurement. To remind you that the present results have not been obtained with the modified settings and that you should repeat the measurement, the result display shows a yellow bar.

All voltage-related parameter values can be entered as **`23 mV`**, **`0.01 V`**, and so forth.

All power-related values can be entered as **`50 mW`**, **`0.04 W`**, **`6 dBm`**, and so on.

All numbers can be entered in decimal notation (**`10000000`**, **`0.0003`**, for example) and scientific/engineering notation (**`1e9`**, **`1.7e-3`**, for example).

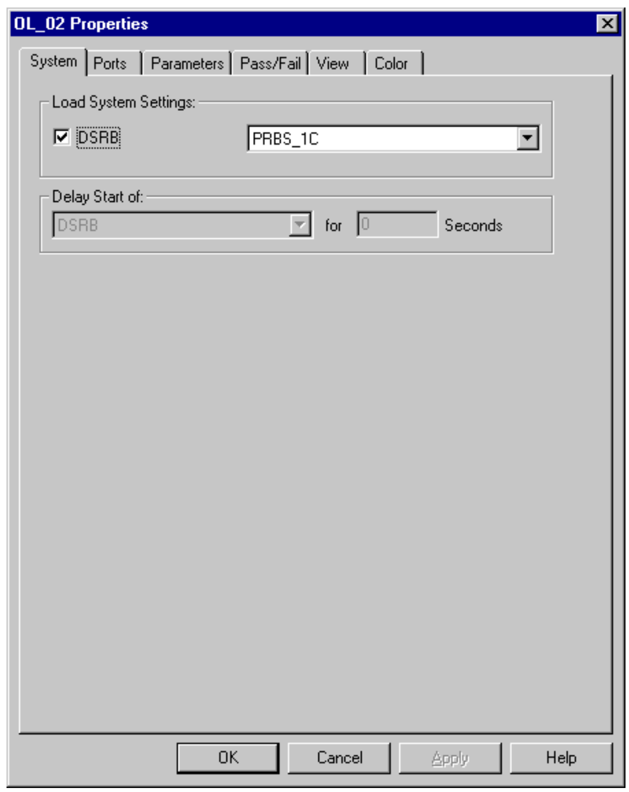
For detailed instructions see

- *"How to Set Up the System to be Used" on page 48*
- *"How to Select the Ports to be Measured" on page 50*
- *"How to Specify the Measurement Parameters" on page 51*

- *"How to Set Pass/Fail Criteria" on page 55*
- *"How to Specify the View" on page 59*
- *"How to Change the Colors of the Graph" on page 62*

How to Set Up the System to be Used

The *System* page of the *Properties* dialog appears automatically if you have set up a new measurement. The *System* page shows one or two systems, depending on your selection when creating the measurement.



For a saved measurement, the *System* page shows the setting that has been used when performing the measurement, as illustrated in the previous figure.

For a new measurement, the systems chosen for the *Workspace* are displayed.

If you have already loaded a setting with the *Agilent 81250 User Software*, then the name of this setting is displayed, and it will be used by default.

If no setting is loaded on the system(s) or not the setting you need, you have to load a setting:

1 Click the check box belonging to the system.

   This activates the setting name field.

2 Choose a suitable setting from the drop-down list.

   When you choose a new system setting, it will be downloaded to the firmware. You have to confirm this action before it will actually be performed.

NOTE For one system only one setting can be loaded at one time. The *Agilent 81250 User Software* and the *Agilent 81250 Measurement Software* therefore always refer to the same setting. If the *Agilent 81250 User Software* is active and you load a different setting from the *Agilent 81250 Measurement Software*, the *Agilent 81250 User Software* will be updated, and vice versa.

If you add or delete ports or terminals or change their connections with the *Agilent 81250 User Software*, then the *Agilent 81250 Measurement Software* will detect such changes when you attempt to run the measurement.

TIP If you have changed the current setting with the *Agilent 81250 User Software* and wish to keep your modifications, save the setting with the *Agilent 81250 User Software* before loading a different one. The *Agilent 81250 Measurement Software* does not save settings.

3 In case of two systems, you can specify a start delay for one of the systems.

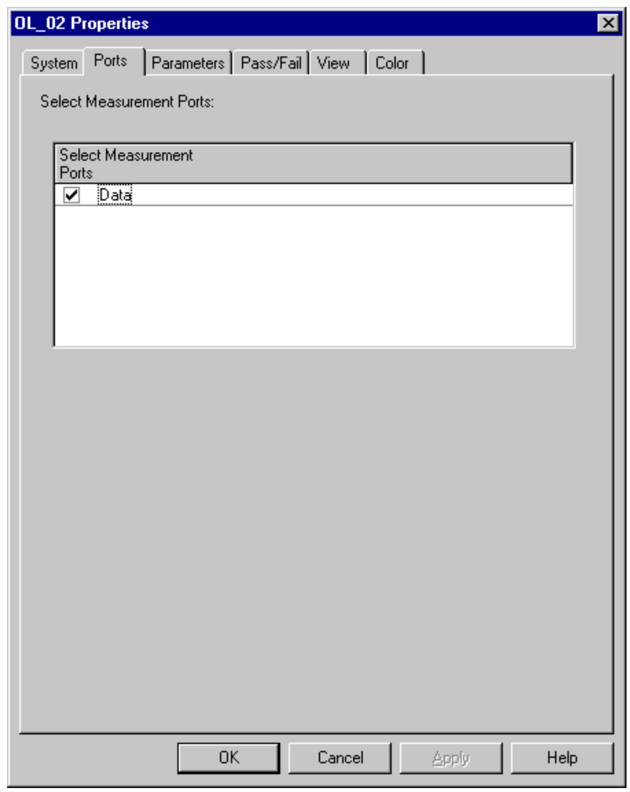
   This may be useful, for instance, to allow a PLL or clock recovery circuit in the DUT to lock onto the incoming data stream.

4 Click *Apply* to accept the modifications without leaving the *Properties* dialog. Or click *OK* to accept the modifications and close the *Properties* dialog.

How to Select the Ports to be Measured

After you have specified the measurement system and the related system setting, you may wish to exclude one or several DUT output ports from the measurement.

1 In the *Properties* dialog, select the *Ports* tab.



The *Ports* page lists all the output ports of the device under test, as defined in the loaded setting. In case of two systems, this is the setting loaded on the analyzing system. By default, all these ports are enabled and will be measured.

This display is not automatically updated if you change the loaded setting by means of the *Agilent 81250 User Software*.

2 Disable the ports that shall not be measured.

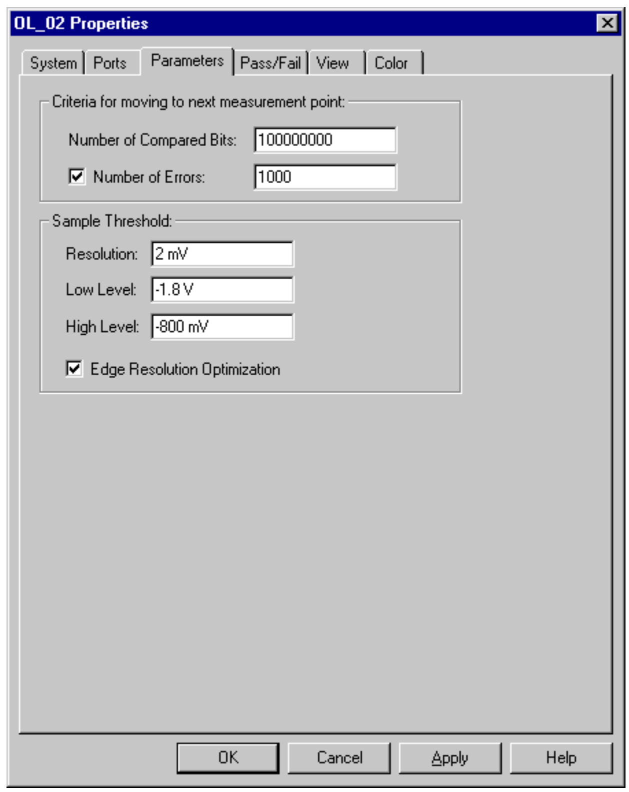
3 Click *Apply* to accept the modifications without leaving the *Properties* dialog. Or click *OK* to accept the modifications and close the *Properties* dialog.

How to Specify the Measurement Parameters

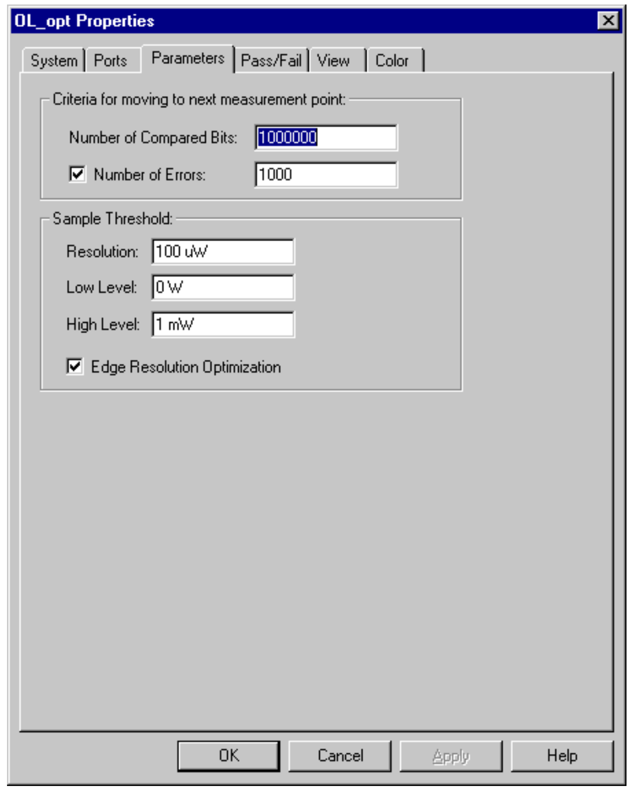
The *Parameters* page of the *Properties* dialog allows you to specify the parameters of the Output Level measurement.

NOTE If you modify the settings of this page, you have to rerun the measurement to update the results.

1 In the *Properties* dialog, click the *Parameters* tab.



If you have created a measurement for optical ports, the *Parameters* page shows power units (Watt, by default). This looks as follows:



Note that you can enter these values also in dBm, such as **`6.5 dBm`**, for example.

2 Inspect and change the defaults, if desired.

For details, see *"How to Specify the BER Measurement Resolution" on page 52* and *"How to Specify the Threshold Resolution" on page 53*.

How to Specify the BER Measurement Resolution

In the upper section of the *Parameters* page, you can control the speed and precision of the BER measurements.

1 Change the *Number of Compared Bits*, if desired.

The default number is one million bits.

A smaller number would reduce the duration of the whole Output Level measurement. A larger number increases the resolution of the measured bit error rates.

NOTE If you keep the default setting, you cannot measure bit error rates below 10^{-6} (one error per 1,000,000 bits). The whole BER region between zero and 10^{-6} would remain unknown.

2 If desired, activate the *Number of Errors* and enter a suitable number.

After this amount of errors, the measurement stops for the current sampling threshold and moves to the next. This allows you to speed up the measurement. Your entry will not be checked; a good value depends on the bit error rates you want to measure. Disable this option if you want measure even high bit error rates precisely.

3 Click *Apply* to accept the modifications without leaving the *Properties* dialog. Or click *OK* to accept the modifications and close the *Properties* dialog.

How to Specify the Threshold Resolution

In the lower section of the *Parameters* page, you can change the range and increment of the analyzer decision thresholds.

1 Set the *Low Level* threshold.

This is the initial threshold.

2 Set the *High Level* threshold.

When this threshold is reached, the measurement stops.

3 Set the *Resolution*.

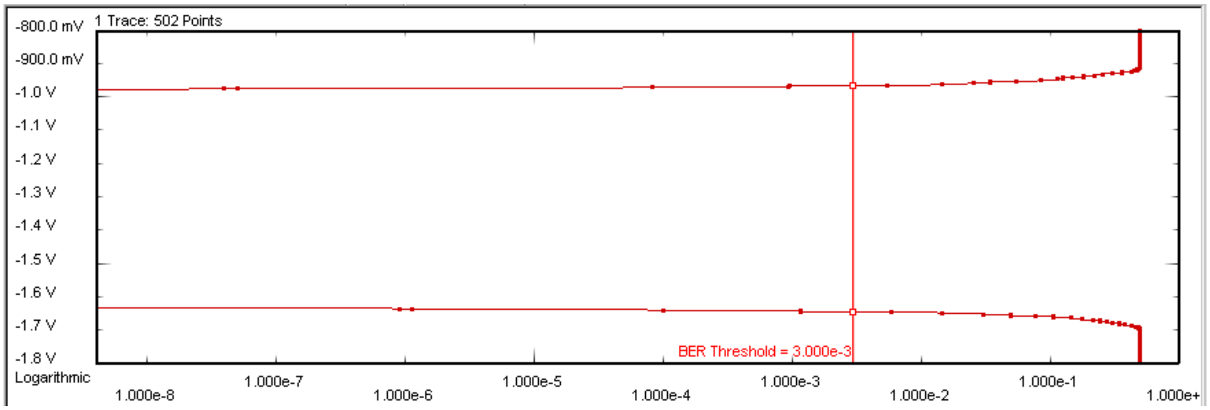
This defines the step width. The minimum step width is hardware-dependent. At the time being, the minimum is 1 mV for electrical measurements.

4 Enable or disable the *Edge Resolution Optimization*.

This option allows you to reduce the measurement duration without sacrificing its precision.

If *Edge Resolution Optimization* is disabled, a fixed resolution is used.

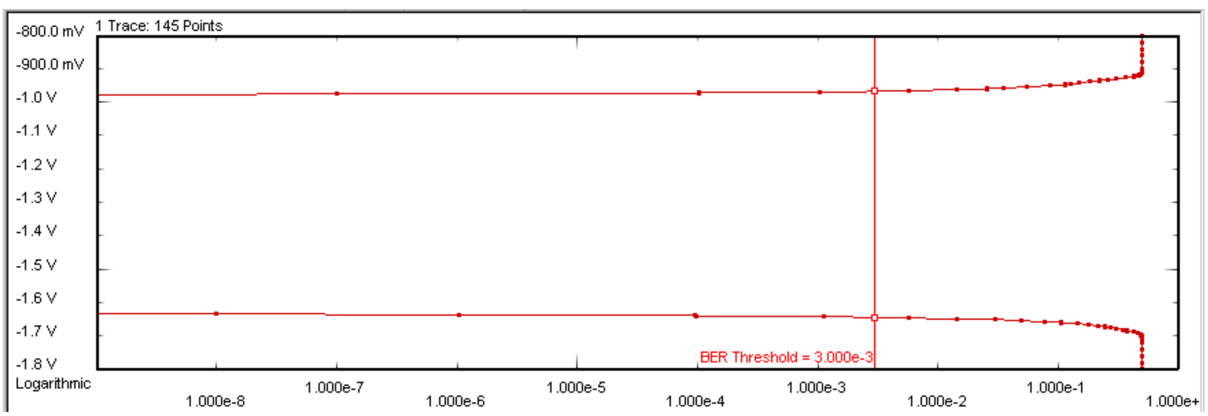
In the following example, a step width of 2 mV was used. This has led to 502 data points per Volt.



If *Edge Resolution Optimization* is enabled, the software first scans the threshold range in relatively coarse steps and determines the areas where the signal produces no edges—that means, where the BER is nearly constant.

Then, the algorithm uses the specified step width for measuring the regions where the BER changes, and a much lower resolution (about one tenth) for measuring the regions where the BER is constant.

This reduces the number of data points to 145, as shown in the figure below.



As you can see from the figures above, *Edge Resolution Optimization* does not sacrifice the precision of the measurement. But it can reduce the measurement duration considerably, especially if you compare a large number of bits at a low data rate.

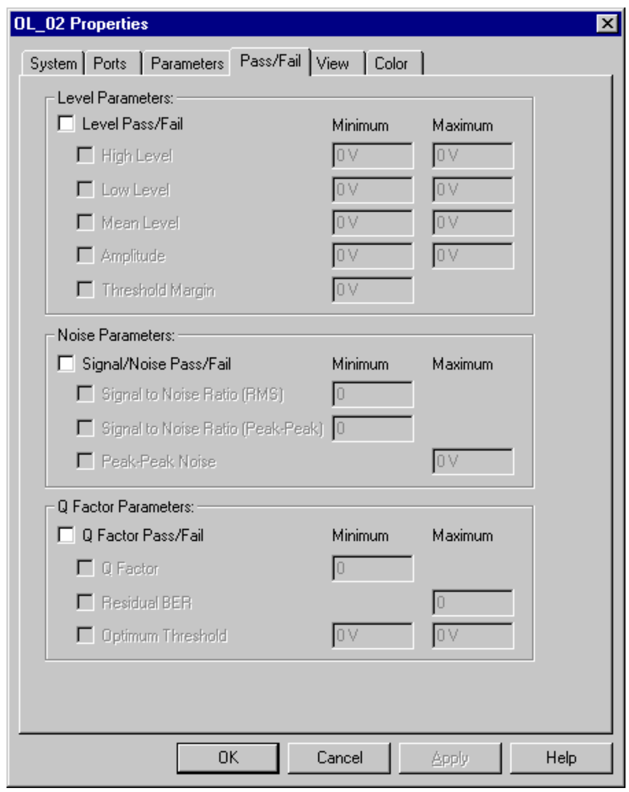
5 Click *Apply* to accept the modifications without leaving the *Properties* dialog. Or click *OK* to accept the modifications and close the *Properties* dialog.

How to Set Pass/Fail Criteria

The *Pass/Fail* page of the *Properties* dialog allows you to specify the criteria which determine whether the DUT has passed or failed the test.

You can change the pass/fail criteria without rerunning the measurement. The software compares the results with the limits after the measurement has finished.

1 In the *Properties* dialog, click the *Pass/Fail* tab.

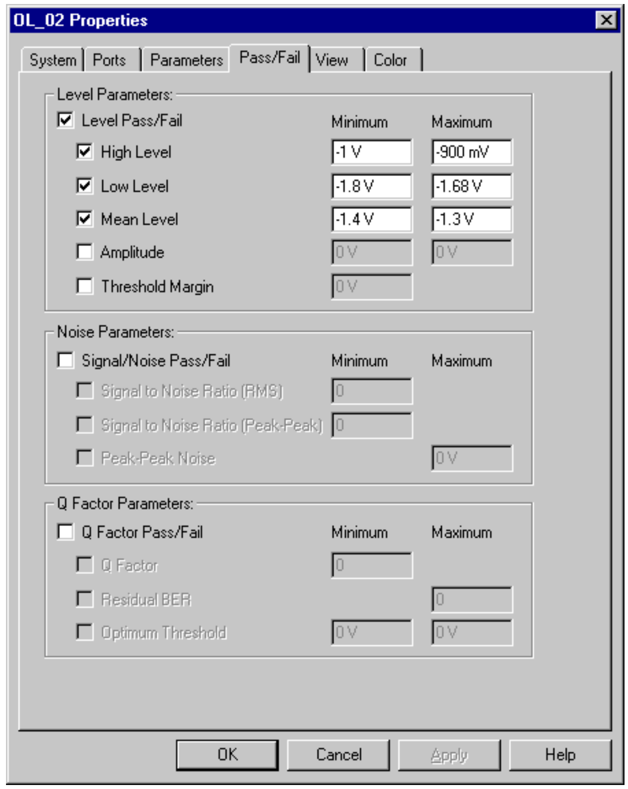


You can set pass/fail limits individually for level, noise, and Q-factor parameters.

2 To enable the limits, click the checkbox of the parameter group.

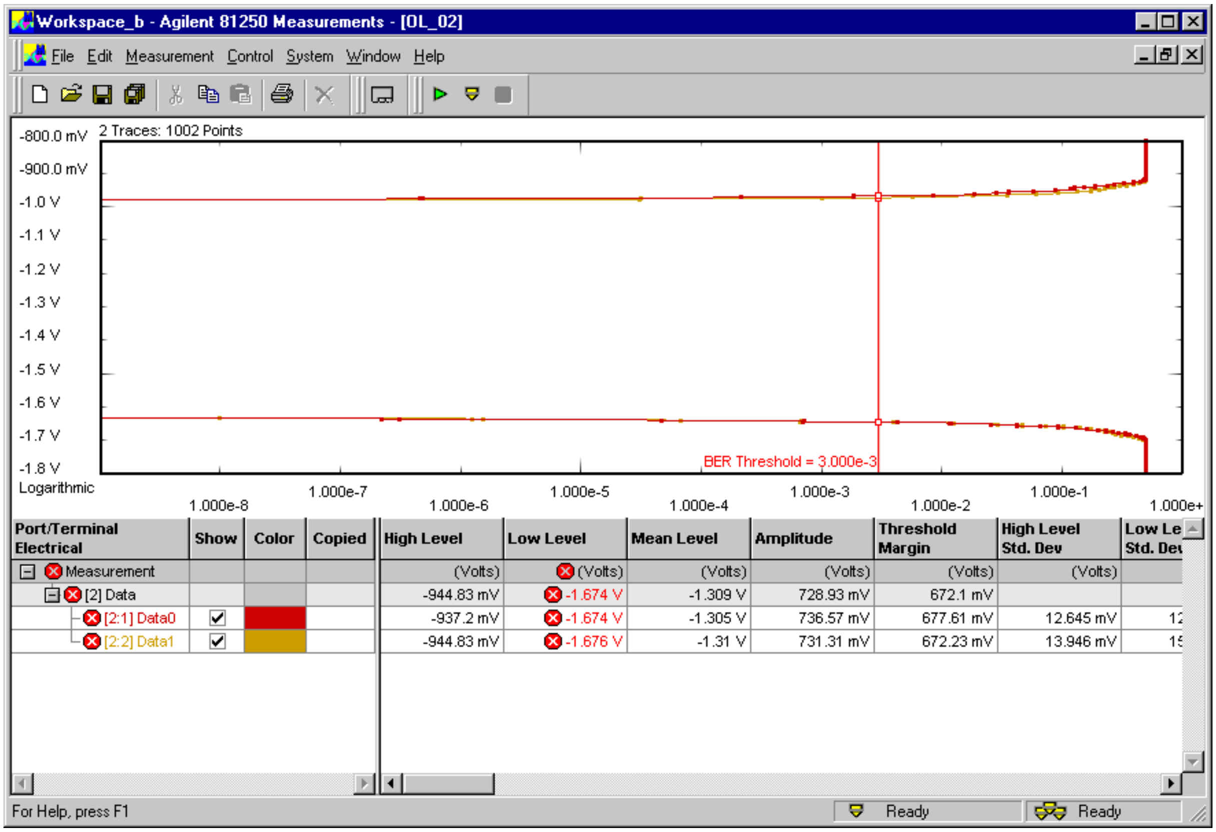
3 Enter the limits as required.

Your setup may finally look as shown below:



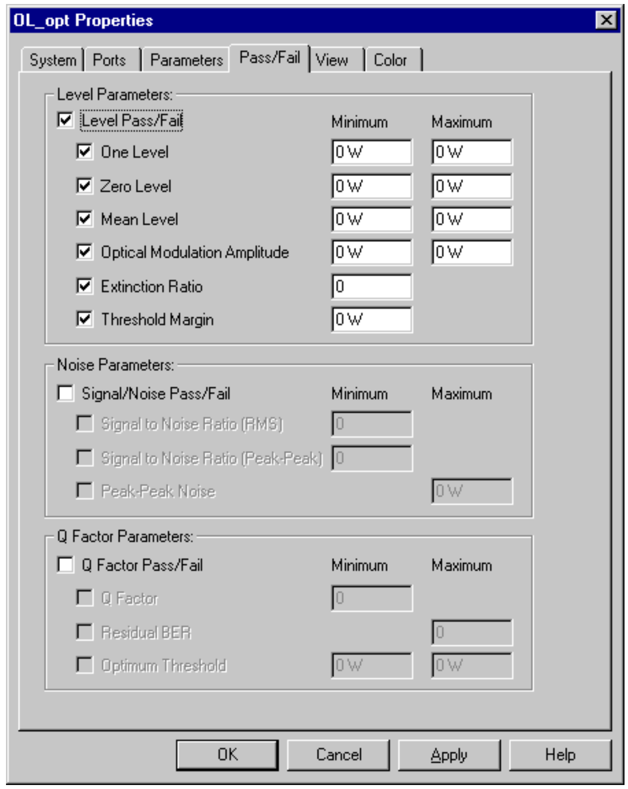
4 Click *Apply* to accept the modifications without leaving the *Properties* dialog. Or click *OK* to accept the modifications and close the *Properties* dialog.

In the following figure, you can see how errors are flagged.



If you compare the Low Level results with the limits we have set on the Pass/Fail page, you will find that the measured results failed the upper pass/fail limit for this parameter.

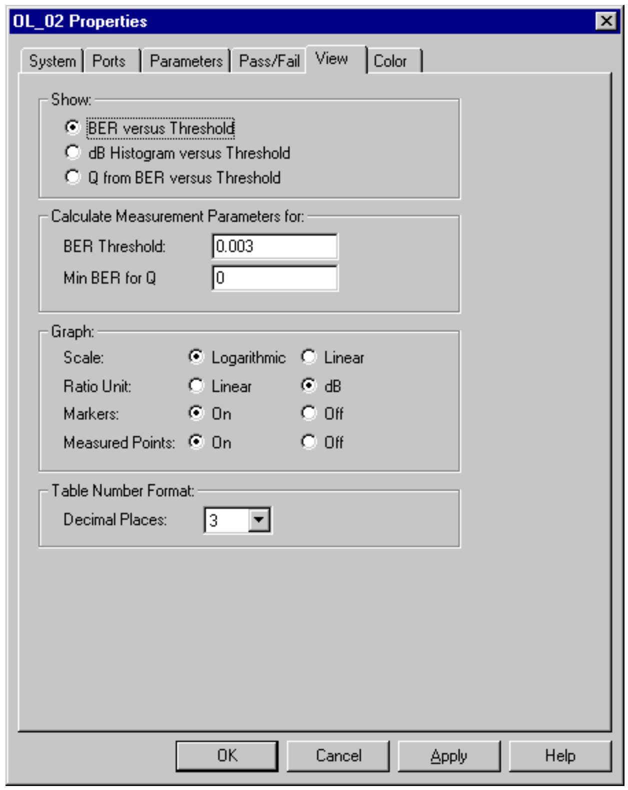
For optical measurements, you can set an additional minimum limit for the *Extinction Ratio*. This looks as shown below:



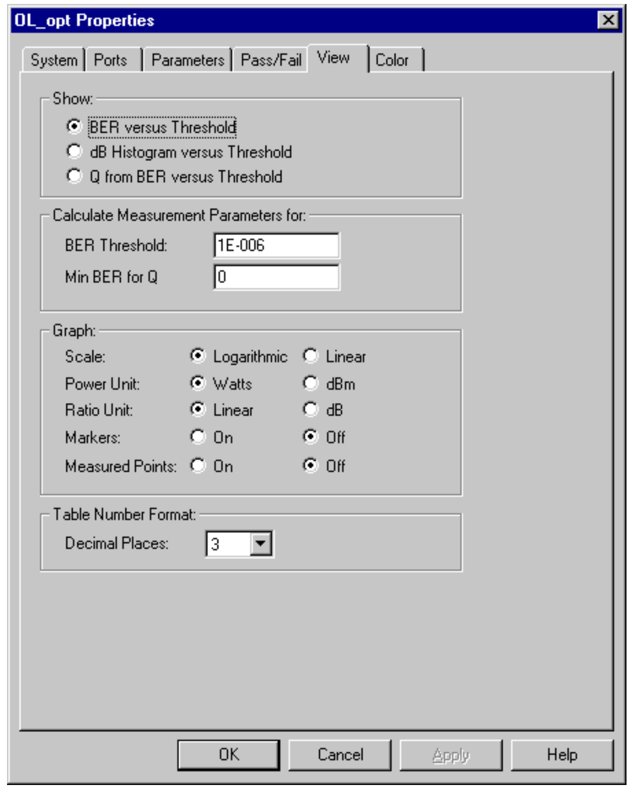
How to Specify the View

The *View* tab of the *Properties* dialog allows you to modify the display of the measurement results.

1 In the *Properties* dialog, click the *View* tab.



If you have created a measurement for optical ports, the *View* page looks as follows:



2 Choose the graph you wish to be displayed. Choices are:

– *BER vs. Threshold*

This graph shows the relationship between the analyzer decision threshold and the resulting BER. It presents the raw data.

– *dBER vs. Threshold*

This graph shows the relationship between the analyzer decision threshold and the derivative of the bit error rate (dBER/dTh). A Gaussian marker allows you investigate the peaks of this graph.

– *QBER vs. Threshold*

This graph shows the extrapolation of the Q-factor and the optimum threshold level from a limited number of measured points.

3 Check and change the two BER thresholds, if necessary.

- *BER Threshold*: This is the bit error rate threshold at which the *Threshold Margin* is determined. This is also the upper threshold for the Q-factor calculations.

  The *BER Threshold* is displayed in the *BER vs. Threshold* graph. There, it can be positioned with the mouse.

- *Min BER for Q*: This is the lower threshold for the Q-factor calculations. It cannot be changed elsewhere—only on this page.

4 Set your preferences for the graphs.

- *Scale*: Refers to the horizontal scales: linear or logarithmic. The scale of the *QBER vs. Threshold* graph is always linear.

- For optical ports, choose the *Power Unit* for the display of the values. Choices are *Watt* or *dBm*.

NOTE *Power Unit* is only available when optical ports are used for the measurement.

- *Ratio Unit*: You can display ratios (such as SNR) linearly or logarithmically in dB.

- *Markers*: Enable/disable the display of markers.

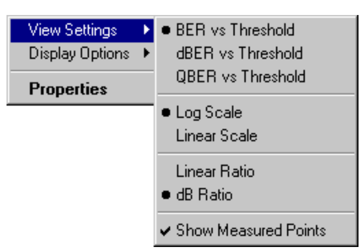
- *Measured Points*: Enable/disable the display of measured points.

5 Choose the number of *Decimal Places*.

  By default, numbers are displayed with three digits. You can increase or decrease that number.

6 Click *Apply* to accept the modifications without leaving the *Properties* dialog. Or click *OK* to accept the modifications and close the *Properties* dialog.

NOTE Many items of this page can also be set conveniently from the *View Settings* submenu of the context menu. This looks as shown below:

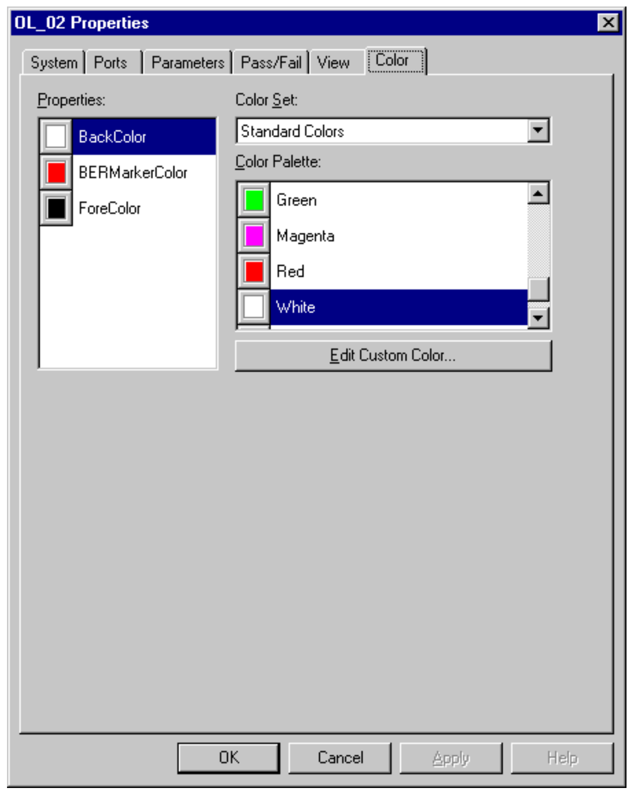


Markers can also be enabled from the *Display Options* submenu, as well as the Zoom option.

How to Change the Colors of the Graph

This page of the *Properties* dialog enables you to customize the colors of the graphical display.

1 Click the *Colors* tab.



You can change:

– The background color of the graphs (default is white)

– The color of the *BER Threshold* indicator (default is red)

– The foreground color of the scales and frame of the graphs (default is black)

2 If you have made any changes, click *Apply*.

This updates the measurement window, and you can immediately check the result.

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